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Evaluation of Consolidation Treatments for the San José Convento Column, San Antonio Missions National Historic Park, San Antonio, Texas

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Abstract
The retreatment of previously consolidated stone has become a common occurrence and an important area of research in the field of architectural conservation. The San José Convento Column within the San Antonio Missions National Historical Park in San Antonio, Texas is a prime example for consideration. Initially analyzed, tested, and treated in 1993 by the Architectural Conservation Laboratory at the University of Pennsylvania, the limestone column is in need of additional treatment. Recent analysis has determined that while the 1993 treatment had been largely successful, microcracks originally present have advanced and surface detachment has worsened, largely due to clay swelling deterioration. Over the past 19 years, further research has been performed on modified ethyl silicates that inhibit clay swelling while restoring the grain-to-grain cohesion of argillaceous stone. In order to determine the most appropriate consolidation treatment for the column, several consolidants including a modified ethyl silicate were tested to determine the most appropriate method for in situ application. Samples, consisting of 2-inch square cubes and 2-inch x 2-inch x 0.2-inch coupons were treated with three different consolidants including a pre-treatment with an anti-swelling agent. Samples were then subjected to physico-mechanical testing to evaluate the effect of these treatments on stone strength, water absorption, and permeability. New methods of assessing the consolidation effects involving resistance drill testing were used to measure depth of penetration and efficacy of application. The information and data obtained from this study will inform the future retreatment of the column needed to resolve the microcracking visible today.

Keywords
argillaceous, consolidation, swelling, drill resistance, limestone

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EVALUATION OF CONSOLIDATION TREATMENTS FOR THE SAN JOSÉ CONVENTO COLUMN, SAN ANTONIO MISSIONS NATIONAL HISTORIC PARK, SAN ANTONIO, TEXAS

Kalen Daniel McNabb

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CHAPTER 1: INTRODUCTION

This thesis proposes to study current consolidation methods for argillaceous limestone and methods of analyzing the efficacy of such treatments by drill resistance testing in order to develop and perform a comprehensive testing program to serve as a basis for treatment recommendations of the San José Convento Column at Mission San José y San Miguel de Aguayo in San Antonio, Texas.

The retreatment of previously consolidated stone has become an increasingly common occurrence and an important area of research in the field of architectural conservation. The San José Convento Column within the San Antonio Missions National Historical Park in San Antonio, Texas is a prime example for consideration. Initially analyzed, tested, and treated in 1993 by the Architectural Conservation Laboratory at the University of Pennsylvania, the column today is now in need of additional treatment. Recent analysis has determined that while the 1993 treatment had been largely successful in stabilizing the active flaking and decohesion of the stone surface, microcracks originally present have advanced and original surface detachment has worsened, largely due to clay swelling deterioration.

It is likely that this deterioration mechanism existed in 1993, but was less visible due to the extent of detachment and flaking. Over the past 19 years, further research has been performed on modified ethyl silicates that inhibit clay swelling while restoring the grain-to-grain cohesion of argillaceous stone. In order to determine the most appropriate consolidation treatment for the column, several consolidants including a modified ethyl silicate were tested to determine the most appropriate method for in situ application.

Specific hypotheses addressed in this study include:

• If the deteriorated masonry limestone of the San José Convento Column is treated with a consolidant, then the grain-to-grain cohesion and strength of the stone will increase while causing minimal change to the vapor permeability and

Figure 1.1 Microcracking seen during 2011 Assessment

absorption of the original stone.

• If the previously consolidated stone exhibited clay-swelling deterioration, then the application of an elastified ethyl silicate consolidant with a swelling inhibitor will further restore grain-to-grain cohesion while limiting swelling of the inherent clays.

• The use of resistance drill testing on prepared laboratory samples of 2-inch cubes should effectively measure the depth of consolidant penetration and the efficacy of the application.

Research undertaken for this study has focused upon the continuing deterioration of the column due to swelling of clays inherent within the stone. Previous theses on the San José Convento Column including those considering the

initial treatment and later efficacy of the treatments were consulted extensively for this study (Brackin 1993, Karas 2011)[1] in addition to published research on this study (Oliver and Ferron, 1997)[2]. Correia's thesis on the consolidation on the Sacristy Window at the Mission San José was used as an example of a thorough stone consolidation-testing program.[3]

Local argillaceous limestone samples similar to the column were taken from the perimeter wall of the mission and previously studied during the initial 1993 treatment tests. These samples have been used for the purposes of this research. These samples, consisting of 2-inch square cubes and 2-inch x 2-inch x 0.2-inch thick coupons were treated with four different consolidants including a pre-treatment with an anti-swelling agent. Untreated and treated samples were then subjected to physico-mechanical testing to evaluate the effect of these treatments on stone strength, water absorption, permeability, and wet-dry cycling. New methods of assessing the consolidation effects involving resistance drill testing were used to measure depth of penetration and efficacy of application on a large boulder recovered from the site.

Durability of the stone was determined by wet/dry cycling coupled with SEM analysis to visualize the interaction of the consolidants with clay particles within the stone. The information and data obtained from this study will inform the future retreatment of the column needed to resolve the microcracking visible today.

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[1] Brackin, A. E., 1994, "A Comparative Study of the Effects of Applying Acrylics and Silanes in Sequence and In Mixture with a Case Study of the Column in the Convento of Mission San José Y San Miguel De Agauyo", Graduate Thesis, Univ. Pennsylvania; Karas, N., 2011, "Evaluation of the 1993 Conservation Treatment of the San José Convento Column San Antonio Missions National Historic Park, San Antonio, Texas", Graduate Thesis, Univ. Pennsylvania.

[2] Matero, F. G. and Oliver, A.B., 1997, "A Comparative Study of Alkoxysilanes and Acrylics in Sequence in Mixture" *Journal of Architectural Conservation*. 2(3), 23

[3] Correia, J. M., 2005 "Treatment Evaluation for the Micritic Limestone at Mission San José Y San Miguel De Aguayo, San Antonio, Texas." Graduate Thesis,. Univ. Pennsylvania.

The conclusions drawn from this work will also contribute to the broader issues of retreatment and life cycle of treatments on previously consolidated stone.

CHAPTER 2: SITE HISTORY AND PREVIOUS TREATMENTS

2.1 SITE HISTORY

The San Antonio Missions Historical National Park contains four historic Franciscan missions originally created during the 18th century. The missions contained within the park were initially established along the San Antonio River and ultimately became the foundation for the city of San Antonio. Within the park lies a portion of the mission of San José y San Miguel de Aguayo, originally established in 1721, that encompasses many of the original structures including the main church dating back to the 1770s. During the 1820s, the San José Mission was formally closed and in 1860 was reestablished by Benedictine monks. During this time, the Benedictines initiated an extensive building campaign, which included removing and rebuilding an internal partition wall of the Convento running east to west. The newly constructed wall featured seven arches and a single octagonal column located near the east entrance of the 1770 church.

These new additions were meant to be interior spaces with the octagonal column located in a stair hall and were constructed out of local calcareous tufa, also known as tufaceous limestone and calcareous sandstone blocks laid in lime mortar. Other more detailed decorative elements, such as the sacristy window, were carved out of a softer micritic white limestone (Brackin 1993). Following the construction of the second story colonnade, the Benedictines abandoned the mission, leaving their recent additions unfinished and unroofed. The mission was largely abandoned until the 1920s when a renewed interest resulted in archaeological excavations on the property and reconstruction and maintenance of the missions.

Figure 1.1 Mission San José and adjoining Convento

Figure 1.2 San José Convento Column, 2011.

CHAPTER 2: SITE HISTORY AND PREVIOUS TREATMENTS

2.2 STONE CHARACTERIZATION

The San José Convento column is constructed out of a locally impure limestone and laid with a gypsum-lime bedding mortar.[1] The entire column is composed of nine limestone drums that reach a height of 7 ft 10 in. The first seven drums form the shaft of the column and are carved out of a golden-brown fine-grained limestone. The eighth drum forms the necking of the column and is made of a grey fine-grained limestone while the capitol is carved from a golden brown limestone.[2] Originally intended to be an interior feature, the column has been exposed to the outdoor conditions for the last 150 years. During the column's early history, it was periodically exposed to cyclical moisture, causing the soluble gypsum in the mortar to dissolve, infiltrate the impure limestone, and recrystallize during evaporation, further spreading sulphate salts throughout surrounding column's masonry and especially along the drum joints. Historic photographs of the column highlight the progressive deterioration of the stone and the subsequent mortar repair treatments. The first treatments to the column are visible in a 1927 photograph and have been identified as gypsum mortar infills of deteriorated and presumably lost or removed stone (Karas 2011). Further mortar repairs were performed during the 1960s and were composed of lime and sand (Brackin 1993, 99). The deterioration of the column became a primary concern following the creation of San Antonio Missions Historical National Park in 1978. In 1987, the deterioration of the column was further monitored and a treatment program was initiated in 1993.

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[1] Karas, N., 2011, "Evaluation of the 1993 Conservation Treatment of the San José Convento Column San Antonio Missions National Historic Park, San Antonio, Texas", Graduate Thesis, Univ. Pennsylvania, 12-13.

[2] Matero, F. G. and Oliver, A.B., 1997, "A Comparative Study of Alkoxysilanes and Acrylics in Sequence in Mixture" *Journal of Architectural Conservation*. 2(3), 23

2.3 PREVIOUS TREATMENTS AND ANALYSIS

2.3.1 1993 ACL Treatment

In 1993 Anne Brackin and the Architectural Conservation Laboratory at the University of Pennsylvania designed and executed a conservation program. Prior to treatment, the column and its deterioration were extensively studied and the masonry, mortar, and patches on the column were analyzed and characterized. The stone was petrographically analyzed to determine the chemical composition of the original material. The golden-brown stone was determined to be an impure limestone with angular quartz in a cryptocrystalline calcite matrix with lesser amounts of iron oxide minerals including goethite and clays. High concentrations of sulphates (SO_4^{2-}) were also detected and were determined to be originating from the

Figure 1.3 Convento Column prior to 1993 Treatment

gypsum repair mortar.[3]

The bedding and repair mortar were determined to contain high amounts of calcium sulfate dihydrate ($CaSO_4 \cdot H_2O$), or gypsum. The active deterioration mechanism was determined to be the dissolution and recrystallization of the water-soluble gypsum binder in the mortar and the infiltration of this material into the stone. The recrystallization of this mineral would exert pressure on the walls of the pores and eventually cause cracking and delamination. The swelling of the inherent clays within the limestone was also determined to be a contributing factor to the deterioration, which were believed to swell during exposure to exterior conditions and would exert further pressure within the stone pores. These processes affected the stone by causing excessive surface friability and delamination of larger fragments of the stone.

Due to the aforementioned decay mechanisms and the observed deterioration of the column, a consolidant was chosen that would deeply penetrate the stone to re-establish the grain-to-grain cohesion and an adhesive or fixative to restore cohesion between the larger grains and flakes not addressed by the consolidant. For these purposes, a sequential treatment of an alkoxysilane consolidant, acrylic adhesive, and a water repellent were determined to be the most practical and effective treatments based on laboratory testing. The treatment program of the column in the convent of Mission San José was performed in four major phases.

Phase 1: Preconsolidation

Phase 1 dealt primarily with the preconsolidation of the column to prevent further loss of material during subsequent treatments. During this phase, the column was extensively documented, and previous repairs and patches were removed.

[3] *Ibid,* 24

Figure 1.4 Phase 1 of 1993 Treatment (ACL 1993)

Gypsum bedding mortar was removed as far back as possible.

A 7.5-15% solution of Acryloid B72 was applied in a 1:1 mixture of xylenes and toluene with Japanese tissue paper to temporarily protect fragile areas. Fine cracks were injected with a 15% solution of B72 while remaining friable areas were applied with a solution ranging from 3.75-7.5%. Blind voids in association with removal of the previous repairs were injected with a grout consisting of 2: 1:1:1.5 (by volume) of a moderately hydraulic lime (Riverton Corp), microballoons (Zeelite spheres, Zeelan Industries), fine silica sand (passing #30 sieve), and water. Three separate poultices consisting of a mixture of ½ rag stuff paper pulp and 3% glycerin were then applied in an attempt to remove residual gypsum salts.

Phase 2: Consolidation

Japanese tissue paper applied previously was removed and the column was consolidated using four gallons of ethyl silicate (ProSoCo Conservare® Stone Strengthener OH100), applied using a low-pressure sprayer. Following this initial application, a gallon of methyl ethyl ketone (ProSoCo Stone Strengthener Solvent) was sprayed on the entire surface of the column to remove any surface accumulation of the ethyl silicate consolidant.

Phase 3: Patching

Large flakes were reattached using a 15% B72 solution and large cracks were injected with a 1:1 mixture of 15% B72 and microballoons. Exposed surfaces of the original stone after patch removal were tooth-chiseled to expose sound stone

Figure 1.5 Column following consolidation and prior to patching (ACL 1993).

and holes were randomly drilled to provide keys for composite mortar patching. Patching consisted of a scratch coat with a 1:3 mixture of hydraulic lime and local mason's sand and a finish coat of a 1:3 mix of sieved hydraulic lime and yellow bar sand colored with pigments to match the original stone (all parts by volume).

Phase 4: Water Repellent

Following a cure time of one month, the patches were roughened and brushed to remove laitance. The stone was then further drilled in still hollow-sounding areas and injected with a 15% solution of B72 and microballoons. After drying for 32 hours, the column was brushed with 32 ounces of methyltrimethoxysilane (Dow-Corning Z-6070) to impart water repellency. Following the completion of the conservation program, a preventative maintenance and monitoring program was established that recommended annual permeability measurements be performed using a RILEM test for water absorption (11.4) and the reapplication of the water repellent every 5 years or as needed based on the measurements.[4]

[4] Brackin, A. E., 1994, "A Comparative Study of the Effects of Applying Acrylics and Silanes in Sequence and In Mixture with a Case Study of the Column in the Convento of Mission San José Y San Miguel De Aguayo", Graduate Thesis, Univ. Pennsylvania, 10.

Figure 1.6 Column Following Treatment in 1994 (ACL 1994)

2.3.2 2011 Post Treatment Assessment

In 2011, a follow-up assessment was designed to evaluate the efficacy of the 1993 stone conservation treatment, [5] This study highlighted a new area of interest within the field of stone conservation to reassess past treatments and possibly propose further consolidation treatment. During the study, Karas re-surveyed the current conditions of the column using ortho-rectified digital photo-montages of each column face and overlaid a graphic conditions assessment based on the graphic

[5] Karas, N., 2011, "Evaluation of the 1993 Conservation Treatment of the San José Convento Column, San Antonio Missions National Historic Park, San Antonio, Texas," Graduate Thesis, Univ, Pennsylvania., 51

Figure 1.7 San AntonioColumn in 2011 (Youngborg 2011)

survey executed in 1993. On site, the original surfaces of the column were hand sounded for active detachment. Samples were taken from the column for scanning electron microscopy examination and petrographic analysis.

The findings indicated that the north elevation of the column displayed the highest level of deterioration with areas of detachment and micro-cracking. Cracks visible in the 1994 image expanded in width and length. Composite repairs on the east elevation are cracked. Cracking was also present on the south and west elevations. SEM analysis suggested that in certain areas the treatments behaved as a mixture after application as the ethyl silicate had reacted preferentially with the MTMOS, which may have reduced bonding to the stone. SEM analysis of the original untreated stone verified the 1993 compositional characterization and highlighted the abundance of clays within the argillaceous limestone. [6]

The conclusion of Karas's study showed that the earlier conservation treatment was successful for the treatment of disaggregation and surficial flaking but also highlighted problems of clay swelling within the column, which is further complicated by the presence of gypsum. A primary concern at the end of the study was the interaction between clay-cemented stones and an ethyl silicate treatment. Previous studies have shown that an ethyl silicate treatment can aggravate damage caused by wet/dry cycling.[7] Recommendations from her study called for further monitoring of the column to perform continual study of the efficacy of the treatment and further laboratory testing of newly available consolidants on samples taken during the 2011 site visit all in preparation for re-treatment

[6] Ibid, 65-69.

[7] Wendler, E., Klemm, D., and Snethlage, R., 1991, "Consolidation and hydrophobic treatments of natural stone", In *Durability of Building Materials and Components: Proceedings of the Fifth International Conference, Brighton, U.K., 7-9 November 1990,* ed. J.M. Baker, O. J. Nixon, A. J. Majumdar, and H. Davies. 203-212. New York: E & F. N. Spon

CHAPTER 3: LITERATURE REVIEW

3.1 INTRODUCTION:

Porous materials that have been exposed to the external environment undergo physical-chemical decay processes that cause the loss of surface and loss of form. This process is particular damaging when it occurs to invaluable works of artistic, architectural, cultural, or historical importance. A combination of several factors, including environmental, physical, and chemical cause the degradation and irreparable loss of the stone fabric of historic structures and monuments. The protection of stone cultural heritage against these processes of deterioration is an essential obligation for the public care of historic monuments. The practice of stone conservation often includes a consolidation intervention to slow weathering and deterioration while attempting to restore the granular cohesion of the stone. This process involves the deposition of new material, often a polymeric compound in inorganic products or organic solvents, into the pores of a stone, allowing the new material to penetrate throughout the deteriorated zone of the substrate and re-establish grain-to-grain cohesive strength without altering other physical properties such as permeability.[1]

3.2 OPTIMAL PROPERTIES FOR A CONSOLIDANT

Successful consolidation depends on several critical properties that affect the performance of the consolidant and its effect on the stone. The identification of these properties has developed within the profession, and in the last decade, organizations such as ASTM International have created a guide for the selection and use of stone consolidants.[2] One of the main functions of a consolidant is to

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[1] Zendri, E.; Biscontin, G.; Nardini, I.; and Riato, S., 2007, "Characterization and reactivity of silicatic consolidants," *Construction and Building Materials,* 21, 1098.

[2] ASTM E2167-01, 2001, "Standard Guide for Selection and Use of Stone Consolidants", ASTM International.

protect against further deterioration while limiting any visual changes to the stone substrate.[3] An ideal consolidant must penetrate deeply within the stone, infiltrating to pores and then solidify to restore the mechanical and chemical properties of the rock, often re-establishing the grain-to-grain cohesion of the particles within the stone.[4] It should not seal the surface of the stone to liquid water and should allow weathered stones to be vapor permeable. Consolidants are often required to meet criteria such as the least chromatic variation, lowest decrease in water vapor permeability, highest liquid water repellence, highest consolidant penetration depth, and an increase in mechanical resistance.[5] Although the desired properties of a consolidant can be generalized, the selection of a consolidant should be chosen specifically on a case-by-case basis. The consolidants should also not encourage biological attack and should be low in toxicity and cost if possible.

3.3 OVERVIEW OF CONSOLIDATION

The history of this practice can be dated as early as the first century B.C., when Vitruvius presented methods of impregnating stone with wax in order to preserve the masonry. Early methods of consolidation involved using easily procurable materials such as oils (linseed), waxes (beeswax) and lime-water.[6]

[3] Hameed, F.; Schillinger, B.; Rohatsch, A.; Zawisk, M.; and Rauch, H. 2009,. "Investigations of stone consolidants by neutron imaging," *Nuclear Instruments and Methods in Physics Research. A. 605, 151*

[4] Erder, E. H., 1995, "Consolidation and Adhesive Repair of Volcanic Tuff Case Study: Conservation of Volcanic Tuff at the Of Stone Church of Mission San Juan Capistrano, Sa Juan Capistrano, California", Graduate Thesis, Univ. Pennsylvania, 10.

[5] Maravelaki-Kalaitzaki, P. Kallithrakas-Kontos, N., Korakaki, D., Agioutantis, Z., and Maurigiannakis, S., 2006, "Evaluation of silicon-based strengthening agents on porous limestones", *Progress in Organic Coatings.* 57, 147

[6] Maxová, Ivana. 2000. "Changes in Properties of Stone Treated with Historical or Modern Conservation Agents." In *9th International Congress on the Conservation and Deterioration of Stone: Proceedings June 19-24 volume II,* edited by Vasco Fassina, 395-402. Amsterdam: Elsevier.

Locally available materials such as these were used consistently throughout the first millennium with little deviation from traditional practices until the nineteenth century. The adverse affects of the Industrial Revolution on Europe's stone cultural heritage were largely responsible for spurring new developments in consolidation during this time.

A variety of organic and inorganic synthetic materials were manufactured to resolve these issues during the 19th and 20th centuries, but often over time these treatments have failed or further damaged the original material. During this time, several important alkoxysilanes were invented including tetraethoxysilane (TEOS), methyltriethoxysilane (MTEOS), and methyltrimethoxysilane (MTMOS).[7] By the 1920s, the use of ethyl silicates resurfaced, although there was much doubt regarding its efficacy as a consolidant and protectant.

In 1956, *The Conservation of Antiquities and Works of Art* was published by Harold Plenderleith and became a seminal book in the field of stone conservation. Within this work, Plenderleith advocated the use of silicon ester for sandstones or siliceous limestones. However, further research following the publication of this work highlighted the effectiveness of ethyl silicates as consolidants for sandstones.

Alkoxysilanes were increasingly used with varying results during the late 1960s and 70s, including the successful use of MTMOS on the Victoria and Albert Museum. In addition to ethyl silicates, a wide array of other materials was also fabricated. However, many new consolidants were not tested in a laboratory setting and ultimately were not proven to age well. Often indiscriminately applied, many of these consolidants produced unpredictable results.[8]

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[7] Wheeler, G., 2005, *Alkoxysilanes and the Consolidation of Stone*. Getty Conservation Institute, 15

[8] Doehne, E., and Price, C. A., 2010, *Stone Conservation: An Overview of Current Research*. Getty Conservation Institute. 2nd Ed.,42.

CHAPTER 3: LITERATURE REVIEW

A more in depth overview of current stone conservation methods has already been produced by Dohene and Price (2005), which elaborates in depth on the materials most often used for stone consolidation including organic polymers, acrylics, and alkoxysilanes.

3.4 ALKOXYSILANES

Due to their inability to penetrate deeply, organic consolidants tend to form hard shallow surface layers, and often fail to achieve a strengthening effect. As such, these types of consolidants have generally been avoided. Alkoxysilanes have been widely used due to their low viscosity and ability to deeply penetrate porous stones as a liquid and then solidify into a stable, inorganic end product within the pores of a stone. When applied to a stone, compressive strength often increases 50 to 100 percent along with increases in modulus of rupture and abrasion resistance.[9]

The chemistry of this compound is composed of a silicon backbone with a combination of alkyl or alkoxy groups attached to the main molecule, creating a variety of tri-, and tetrafunctional alkoxysilanes compounds. These types of compounds are generally low in toxicity, and have low to moderate reactivity in water. During hydrolysis, amorphous silica is deposited within the pores of a stone and alcohol is created as a by product. [10]

Wheeler (2005) has written an excellent history of the development and rise of ethyl silicate consolidants in the United States and the United Kingdom during the 20th century. This source provides a good explanation of the chemistry of alkoxysilanes and their importance and application within the field of conservation.

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[9] Oliver, A. B., 2002, "Variable Performance of Ethyl Silicate Consolidated Stone at Three National Parks," *APT Bulletin,* vol 33. No. 2, 94

[10] Wheeler, G., 2005, *Alkoxysilanes and the Consolidation of Stone*. Getty Conservation Institute, 15

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Today, alkoxysilanes have been widely utilized in the field of conservation and have been commercially marketed. Common alkoxysilanes used in commercial consolidation products include the two silanes methyltrimethoxysilane, $CH_3Si(OCH_3)_3$, (MTMOS), methyl triethoxysilane, $CH_3Si(OC_2H_5)_3$, (MTEOS,) and the ethyl silicate tetraethoxysilanes, $Si(OC_2H_5)_4$, (TEOS). The effect of consolidation for these three compounds is the formation of a polymer network within the stone consisting of atoms of silicon and oxide. The tetra functional monomers form a rigid polymer network characterized by short distances between single junction points.[11]

Proprietary products on the market today often use different combinations of these alkoxysilanes primarily with acrylics or other copolymer to create the varying properties needed of a consolidating gel. The significant drawbacks of these compounds include their tendency to crack during shrinkage and drying and their poor chemical bonding to calcite grains. [12] The tendency of these products to crack is largely a function of the brittle polymer network and short distances between junction points.

TEOS, commonly referred to as ethyl silicate, is a widely used alkoxysilane that has been proven to have good depth of penetration of up to 5 cm in limestones and sandstones.[13] A perusal of current literature highlights the popularity of TEOS consolidants and ethyl silicate/silane mixtures within the conservation field. After application on a stone substrate, ethyl silicates undergo hydrolysis with water within

[11] Škrdlantová, M.; Kotlik, P.; and Dyková, B. 2004, Modification of Stone Consolidants Based on Organosilicone Compounds." in *Proceedings of the 10th International Congress on Deterioration and Conservation of Stone: held in Stockholm, Sweden,* 27 June - 2 July 2004. Editors Kwiatkowski, D. & Löfvendahl, R, 291.

[12] Kalaitzaki-Maravelaki P., Kontos-Kallithrakas N., Korakiki D., Agioutantis Z., and Maurigiannakis, S., 2006, "Evaluation of silicon-based strengthening agents on porous limestones" *Progress in Organic Coatings* 57, 140

[13] Brackin, A. E., 1994, "A Comparative Study of the Effects of Applying Acrylics and Silanes in Sequence and In Mixture with a Case Study of the Column in the Convento of Mission San José Y San Miguel De Aguayo", Graduate Thesis, Univ. Pennsylvania, 50.

the pores and water vapor in the atmosphere, forming silanol with Si-OH groups. Ethanol is also formed as a by-product, which evaporates without leaving damaging residues. Following this, dehydration and condensation reactions allow the silica gel to become deposited within the pores of a substrate. The silica gel also reacts with hydroxyl groups that exist within the pores, restoring the natural binder lost during weathering.[14] The formed silica molecules are chemically similar to the silicate minerals within the stone, providing compatibility with stones having a silicate-based composition. [15] However several significant drawbacks of TEOS exist. The silica molecules formed during hydrolysis within the pores of a stone display no inherent affinity to calcite grains and carbonate materials and may act as an inhibitor of polymerization.[16]

Conservare® OH100 is a widely available commercial alkoxysilane product marketed within the United States. Produced by Prosoco in the United States, Conservare® OH100 is a non-hydrophobic consolidant and an oligomeric TEOS in a toluene solvent with a dibutyltindilaurate catalyst.[17] This catalysts becomes activated within OH100 by atmospheric relative humidity and the water vapor present within the stone. This product, produced in Europe as Wacker OH, does not contain any added solvents, and have been in development since the early 1970s. Advertised to penetrate deeply and to retain a substrate's water vapor permeability, this product has been widely used within the field and has performed favorably on stone,

[14] Sandrolini, F., Franzoni, E., and Pigino, B., 2012, "Ethyl silicate for surface treatment of concrete- Part I: Pozzolanic effect of ethyl silicate," *Cement & Concrete Composites,* 34, 306.

[15] Rodrigues, J. D., 2001, "Consolidation of Decayed Stones: A delicate problem with few practical solutions." *Historical Constructions.* P.B. Lourenco., P. Roca (Eds) Guimaraes,, 7

[16] *Ibid*,, 8-9

[17] Ferron, A., 2007, "The Consolidation of Earthen Surface Finishes: A Study of Disaggregating Plasters at Mesa Verde National Park", Graduate Thesis, Univ. Pennsylvania, 55.

concrete, stucco and brick.[18] When applied to a surface, gel times of the consolidant range from twelve to twenty-four hours, and when cured imparts a degree of water repellency due to the fact that the alkoxy groups are immiscible with liquid water. However this water repellency diminishes over time as alkokysilanes and alkoxy groups further hydrolyze and the methyl ethyl ketone solvent evaporates. .[19]

Despite their widespread usage, ethyl silicate consolidants have three main drawbacks, which include poor reactivity with carbonate stones, slow reactivity, and the significant cracking observed during shrinkage and drying. The effect of applying TEOS to limestone has also been studied extensively in the last 50 years. Plenderleith, in a later edition of his 1956 work, originally noted that ethyl silicates might not perform as well on fine-grained limestone. When an ethyl silicate is applied to carbonate stones, the silica gel will precipitate within the pores of the stone and create a weak bond with the surrounding material.[20]

Wheeler, Fleming, et al. (1992) noted that the addition of silane coupling agents to MTMOS promoted a substantial strength increase for both limestone and sandstone but caused darkening of the original substrate. Wheeler showed that the condensation reaction that gradually removed MTMOS and created silicon polymers was dramatically affected by calcite. Quartz, alternatively, was shown to have little affect on the condensation or hydrolysis reactions, indicating that quartz sandstones were more successfully consolidated by MTMOS. [21] Treatment with alkoxysilane

[18] PROSOCO, Product Data Sheet "Conservare® OH100 Consolidation Treatment"

[19] Weaver, *Alkoxysilanes and Consolidation*, pg 59

[20] Sandrolini, F., Franzoni, E., and Pigino, B., 2012, "Ethyl silicate for surface treatment of concrete- Part I: Pozzolanic effect of ethyl silicate," *Cement & Concrete Composites,* 34, 306.

[21] Danehey, C, Wheeler, G. S., and. Su, S-C. H., 1992, The influence of quartz and calcite on the polymerization of methyltrimethoxysilane." in *Proceedings of the 7th International Congress on Deterioration and Conservation of Stone: held in Lisbon, Portugal, 15-18 June 1992*. Eds Rodrigues, J. D.; Henriques, F.; Jeremias, F. T., Laboratório Nacional de Engenharia Civil

consolidants is also irreversible and aging tests have revealed significant decreases in effectiveness of ethyl silicates after ten years.[22]

In 1996, the Eighth International Congress on the Deterioration of Stone focused on this discussion and examined the possible failures and incompatibility of using ethyl silicate consolidants on calcareous stones. Despite the apparent contradiction, ethyl-silicates have been used on carbonate materials in a variety of projects. This issue illustrates the need for further exploration as these consolidants are often used in the absence of a more appropriate and optimum consolidation product.[23]

3.4.1 Elastified Ethyl Silicates

In the last two decades there have been considerable advancements in the use of alkoxysilanes on clay-rich stones, and the use of this compound on limestone versus quartz sandstones. Recent advancements and the creation of nano particle-modified silanes have combined to create a less brittle film and reduce cracking commonly seen on treatments.[24] The elastomerization of the ethyl silicate compound by the addition of silane molecules allows for longer polyester sequences and a greater flexibility.[25] During consolidation, linear siloxanes will link up within the larger silicate networks in the gel, creating a thin elastic film among the micropores

[22] Oliver, A. B., 2002, "Variable Performance of Ethyl Silicate Consolidated Stone at Three National Parks," *APT Bulletin,* vol 33. No. 2, 95

23 Rodrigues, J. D., 2001, 8

[24] Wendler, E., 1997, "New Materials and Approaches for the Conservation of Stone"In: *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures.* Report of Dahlem Workshop, Berlin, 3-8 March 1996, ed. Baer, N., and Snethlage, R., 182-96. New York: Wiley, 1997.

[25] Boos, M., J. Grobe, G. Hilbert, and J. Muller-Rochholz. 1996. Modified elastic silicacid ester applied on natural stone and tests of their efficiency. In *Proceedings of the 8th International Congress on Deterioration and Conservation of Stone: Berlin, 40, Sept,-4, Oct 1996, ed.* J. Riederer, 1179-85

that binds adjacent components together by creating bridges to the larger gel flakes.[26] Alternatively, it has also been shown that the incorporation of di-functional and even tri-functional monomer esters of alkyltrialkoxy or dialkyldialkoxysilanes into the polymer network can prolong the interjunction distances and reduce brittleness. This process is often referred to as an inner plastification. [27]

Elastified ethyl silicates have been applied successfully to a variety of stones including granites, porous limestones, and sandstones (Kim et al. 2008, Maravelaki-Kalaitzaki *et al* 2006, Maravelaki-Kalaitzaki 2008). Elastified ethyl silicates have also been combined with an adhesive coupling agent such as propyl amino silane to improve its binding ability in soapstones and greenschists.[28] This type of modified ethyl silicate has not been widely used and is still being studied within the field.

The creation of a commercial elastified version known as Remmers KSE 300 E has further spread the use of this modified ethyl silicate, especially in the last five years. This product, produced by Remmers UK, is an elasticized stone strengthener on a silicic acid ethyl ester base with a 30% gel deposit rate. This product differs from more conventional ethyl silicate consolidants by providing a moderate E-modulus increase and having a high penetration depth.[29]

KSE 300 E was used specifically by Barajas et al. 2009, on Aztec andesite

[26] P. Maravelaki-Kalaitzaki, N. Kallithrakas-Kontos b D. Korakaki, Z. Agioutantis, S. Maurigiannakis "Evaluation of silicon-based strengthening agents on porous limestones" *Progress in Organic Coatings.* 57, 141

[27] Škrdlantová, M.; Kotlik, P.; and Dyková, B. 2004, Modification of Stone Consolidants Based on Organosilicone Compounds." in *Proceedings of the 10th International Congress on Deterioration and Conservation of Stone: held in Stockholm, Sweden,* 27 June - 2 July 2004. Editors Kwiatkowski, D. & Löfvendahl, R, 292

[28] Storemyr, P; Wendler, E., and Zehnder, K., *Weathering and Conservation and Greenschist used at Nidaros Cathedral (Norway)*.Lunde, Ø. & Gunnarsjaa, A. (eds.): Report Raphael II Nidaros Cathedral Restoration Trondheim Norway 2000. EC Raphael Programme – European Heritage Laboratory. Report no. 2/2001, The Restoration Workshop of Nidaros Cathedral, Trondheim, Norway

[29] Remmers UK, Technical Information Sheet, "KSE 300 E"

monolith sculptures in order to consolidate the stone and organic pigments painted on the surface. These monoliths were analyzed and discovered to have small proportions of smectite. Analysis after impregnation with KSE 300 E showed that the consolidant generated a mirco-porosity within the stone while creating a smoother texture on the surface of the stone.[30]

3.4.2 Anti-Swelling Inhibitors

Clay-bearing stones are often consolidated due to their tendency to deteriorate faster than non-argillaceous stones. This deterioration has been attributed to the stresses that are created during the swelling and shrinkage of the clay minerals within the stone.[31] The process of swelling is a result of the layer structure of the clay minerals and the cations that are absorbed to maintain charge equilibrium. Swelling can occur in two phases, either as inner-crystalline swelling, or as osmotic swelling. Osmotic swelling results from the difference in ion concentration at the surface of the stacked layers and within the pore water.

The basic structure of all clay minerals is composed of six member-interconnected rings of SiO_4^{-4} tetrahedra that form a sheet structure. Three oxygen atoms within each tetrahedra are connected to adjacent tetrahedra, creating the basic unit of $Si_2O_5^{-2}$. Commonly, a hydroxyl ion, OH^- is bonded to the center of the six member interconnected ring and other cations, such as Mg^{2+}, Fe^{2+}, and Al^{3+}, bond to the free oxygen ion on the silica tetrahedron. Often, Mg^{2+} and Al^{3+} replace Al^{3+} and Si^{4+}, respectively, creating a charge imbalance, which is compensated by the addition of Ca^{2+}, Na^+, and K^+. These exchangeable cations rest on the surface of the

[30] Barajas, M.; Lima, E.; Lara, V.H.; Vasquez Negrete, J.; Barragan, C.; Malvaez, C.; and Bosch, P. "Effect of organic and inorganic consolidation agents on Tlaltecuhtli monolith," *Journal of Archaeological Science*, 36 (2009), 2250-2251

[31] Jimenez Gonzalez, I., Scherer, G.W., 2004, "Effect of Swelling Inhibitors on the Swelling and Stress Relaxation of Clay Bearing Stones", *Environmental Geology,* 46(3), 366

layers between individual sheets and strongly bond the negatively charged sheets. Van der Waals attraction between the sheets also bonds the layers together.[32]

When exposed to water, the cations hydrate and concentrate midway between the individual layers, widening the spacing between the layers and weakening the bonds. The polarity of water molecules leads to this swelling as the molecules orient their negative dipoles to the cation, further weakening the electrostatic attraction between the layers. As water absorption increases, the spacing between the phyllosilicate sheets increases, causing visible expansion, and swelling stress is induced. Ultimately, intercrystalline swelling is well known in readily expandable clays such as montmorillonite, vermiculite, and smectite.[33]

Osmotic swelling of certain clay types depends on the ionic concentration, type of ion exchange, and the pH of water within the pores. This type of swelling can occur over larger distances and result in the complete separation between layers. This type of swelling is due to the difference in concentration between the ions attracted to the surface of the tetrahedra sheet and the ions within the pore water. Due to the presence of positive ions bonded closely to the surface, a high negative potential exists at this location, which decreases with increased distance. When the potentials from two opposite layers overlap, swelling occurs. This type of swelling is often visible when an overburden pressure is relieved and the clays expand in response to the removal of the load. During expansion, water easily enters between the expanded layers, causing further expansion until the ion concentrations are

[32] Madsen, F. T. and Muller-Vonmoos, M. "The Swelling Behavior of Clays" *Applied Clay Science* 4 (1989) 143-156

[33] Helmi, F. M. "Geogyptology of Al-Muzawaka Tombs, Dakhla Oases, Egypt", in. *9th International Congress on Deterioration and Conservation of Stone*, eds. V. Fassina (Elseview Science B.V., Amsterdam, 2000) 99- 117.

balanced out. [34]

Wheeler 2005 details the issues when applying consolidants to clay bearing stones, and the variable reported strength increase of the stone when an alkoxysilane is applied. Tentatively, Wheeler states that the presence of clays within a limestone improves the performance of a stone consolidated with alkoxysilanes. Alternatively, clays within sandstones have a negative effect on consolidated masonry. Ultimately, the structure of the clays inherent within a stone are important, as the structure of different clay groups may affect their ability to be consolidated.[35]

Wendler and Snethlage showed that the swelling and shrinkage of clays could be reduced with the application of α−ω diamino alkanes.[36] This compound contains molecules containing amine groups at the end of each alkane chain, which allows the molecule to adhere to adjacent sheets of particles within the clay structure, binding them and limiting expansion.[37] However, further research has shown that these molecules are randomly distributed, and do not allow for binding to all those sites.[38] Current research suggests that a variety of surfactants with different molecular sizes may significantly perform better than any single molecule.

Currently, several anti-swelling agents are commercially produced for the purposes of stone and earth consolidation. Funcosil® Antihygro® produced by

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[34] Madsen, F. T. and Muller-Vonmoos, M. "The Swelling Behavior of Clays" *Applied Clay Science* 4 (1989) 143-156

[35] Wheeler, G., 2005, *Alkoxysilanes and the Consolidation of Stone*. Getty Conservation Institute, 43-44.

[36] Wangler, T. and Scherer, G.W., 2009, "Clay Swelling Inhibition of α,ω-diaminoalkanes in Portland Brownstone" *Journal of Materials Research*. 24, 1646

[37] Wendler, E., Klemm, D. D., and Snethlage, R., "Consolidation and hydrohobic treatment of natural stone", in *Proc. 5th Int. Conf. on Durability of Building Materials and Components*, eds. J.M. Baker, P.J. Nixon, A.J. Majumdar, and H. Davies (Chapman & Hall, London, 1991) 203-212

[38] Wangler, T., Wylykanowitz, A.,, and Scherer, G.W., 2006, "Controlling stress from swelling clay", *Measuring, Monitoring, and Modeling Concrete Properties,* 7, 703-704.

Remmers is one such product that is reported to reduce clay swelling up to 50% without influencing water absorption and the mechanical properties of the stone.[39] Funcosil® Antihygro® contains buthyl diammonium chloride (BDAC), a surface-active agent in aqueous solutions. This compound interacts with the clay minerals within a stone exchanging the cations in the clay with ammonium and alkyl groups, limiting expansion and reducing swelling.[40] This product, in combination with *Funcosil® SAE 300E*, has been used in combination as a treatment that reduces the deterioration by reducing swelling and consolidating fragile surfaces.

Muller and Riedl 2008 tested volcanic tuff applied with these products by measuring the depth of penetration and the hygric dilation of the tuff. Although a combination of Funcosil® Antihygro® and KSE 300 E is generally successful on argillaceous limestone and sandstone, the application of the consolidant was found to counteract the swelling reducer.[41] When applied to earthen finishes, the combination of an anti-swelling agent and an elastified ethyl silicate was found to have increased stability under the conditions of wet-dry cycling but significantly altered the surface texture and finish.[42] The application of this combined treatment on argillaceous stone is likely to be more successful due to the inherent hardness of the quarried stone.

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[39] Remmers 2007. Web site: www.remmers.co.uk

[40] Muller, U., and Riedl, M. "Volcanic Tuff From Ettringen, Germany and its Interaction with Agents used for Stone Conservators", in *Proc. 11th International Congress on Deterioration and Conservation of Stone*, eds. J. W. Lukaszewicx, and P. Niemcewicz (Nicolaus Copernicus University Press, Poland, 2008) 1001-1009.

[41] Muller, U., and Riedl, M. "Volcanic Tuff From Ettringen, Germany and its Interaction with Agents used for Stone Conservators", in *Proc. 11th International Congress on Deterioration and Conservation of Stone*, eds. J. W. Lukaszewicx, and P. Niemcewicz (Nicolaus Copernicus University Press, Poland, 2008) 1007-1009.

[42] Ferron, A.; and Matero, F.G.. "A Comparative Study of Ethyl-Silicate-Based Consolidants on Earthen Finishes". *Journal of the American Institute for Conservation,* 50(1), 51

3.5 ANALYTICAL TECHNIQUES

The application of a consolidant to a stone must be studied to determine the appropriate method and the efficacy of such treatment. Penetration depth of the consolidant in stone is a key parameter when different consolidants are being analyzed, and several methods exist to measure this parameter. The evaluation of stone consolidation has largely been divided into two main categories: 1) Studies that characterize the stone after treatment has taken place, and 2) Studies that focus and measure long term performance of the treatment. Minimally destructive and non-destructive techniques can be used to effectively measure and evaluate both of these aims.[43] Techniques such as drilling resistance and ultrasonic pulse velocity testing are non-destructive techniques that offer new insight into the success of previous treatments. For the purposes of this study, drilling resistance will be focused on and explored in depth.

3.5.1 DRILLING RESISTANCE

Drilling resistance is a minimally destructive technique that is used to indirectly measure the cohesive properties of stone by detecting the force required to drill several millimeters into a material. This method of analysis is based upon the fact that degradation of a material results in significant loss of strength in the outermost layers of stone.[44] Drilling resistance systems are able to sensitively measure the force required to reach a specified depth while the rotational speed and penetration rate of the instrument are constant (Pamplona 2007).

The history of this technique dates to 1908 and much of the early history

[43] Scahn, Helene, Rapport från Riksantikvarieämbetet, 2006, *Non-Destructive Field Tests in Stone Conservation: Field and Laboratory Tests*,4., 16

[44] Exadaktylos, G., Tiano, P., and Filareto, C., 200, "Validation of a Model of Rotary Drilling of Rocks with the Drilling Force Measurement System", *Journal for Restoration of Buildings and Monuments*. 3.

of this apparatus has been previously discussed by Pamplona et al. 2007. Drilling resistance has long been used in the preservation field for in-situ analysis of historic wooden structures. Its use in assessing stone treatment is a relatively new application. However, in the last decade there has been advancement in micro drilling technology with the creation of the Drilling Resistance Measurement System/Drilling Force Measurement System (DRMS/DFMS) in 2001. The system is composed of the drilling device and the electron unit, often accompanied by a tripod to ensure correct positioning. The mechanical instrument contains two motors that position and turn the drill bit, and a load cell that measures the force required to drill. The graph produced by this instrument shows the variation of the force as a function of the penetration depth of the drill. The test can be performed with a variety of parameters that remain constant during testing, including rotational speed from 100 to 1200 rpm, and a penetration rate from 1 to 40 mm min^{-1}.[45] Typically, DRMS equipment uses a portable drill with a rotational speed with a 5mm ceramic drill bit and sensors that measure the force needed to advance a drill into a given material.[46] Three millimeter drill bits can also be used if it is necessary to reduce the drill force.[47]

Microdrilling has previously been used to trace decay profiles and evaluate stone treatments against strength parameters. Lotzmann and Sasse 1999 analyzed drilling resistance against traditional bending tests. Samples of 3 sandstones were applied by capillary action with either a polyeurethane-based water repellent or an

[45] Del Monte, E., and Vignoli, A. "In Situ Mechanical Characterization of the Mortar in Masonry Buildings with DRMS",on *Site Assesment of Concrete Masonry and Timber Structure,* SACoMaTiS 2008 International RILEM Conference, 1-2 September 2008 Varenna LC. Como Lake, Italy.

[46] Price and Doehne. *Overview*, pg. 7

[47] Pamplona, M; Jocher, M; Snethlage, R.; and Barros, L. A., 2007 "Drilling Resistance: Overview and Outlook" Z. dt. Ges. Geowiss. 158, 671

epoxy with elastified segments to samples of 50 x 50 x 100mm. This study did not indicate a direct correlation between drilling resistance and bending strength but was able to determine the different relative strength properties of the applied water repellents.

Pamplona et al. 2007 further explored the correlation between drilling resistance and bending strength using HARDROCK equipment. Depth of penetration tests were performed on Anca limestone blocks treated with 4.5% Paraloid B72 (acrylic resin), ACS 2001 (arcylic resin), or Tegovakon (ethyl silicate) applied by brush and an untreated control. Drilling resistance measurement from this method indicated that the ethyl silicate consolidated to a depth of 15mm, with slight strength increase up to 30mm while ACS 2001 was shown to create a much harder surface film at 3mm and did not penetrate as deep as the ethyl silicate. Furthermore, the consolidation capacity obtained by laboratory tests directly correlated with a strength parameter such as bending or tensile strength. Samples tested for this method were Anca limestone blocks treated with Tegovakon V, Paraloid B72, and a cycloaliphatic epoxy resin EP 2101 diluted in a 1:1 mixture of toluene/xylene, applied by full immersion. Drill holes were made within the cured samples and average drilling values (N) were compared with bending strength (MPa). This study showed that there is a correlation between drilling force and drilling strength for treated limestone.

Currently there exists no standard for performing drill resistance measurements. However, many studies have sought to develop the appropriate parameters necessary for comparable and reproducible data. Recently, there has been increased research on studying the effectiveness of applied consolidants specifically using the DRMS drill produced by SINT Technologies. However, the drill settings vary among the different studies. De Clercq and De Zanche 2008 used the drill to

identify the effectiveness of an ethyl silicate consolidant applied to a brick. Using the DRMS, each treated substrate was drilled to a depth of 4.5 mm at 100rpm and a penetration rate of 25mm min^{-1}.[48] Pinto and Delgado Rodrigues 2008 used the DRMS to study consolidant performance in soft limestone samples of 10x5x3 cm. Readings were taken using a 5mm diameter drill with a 100 rpm rotation speed and a 20mm min^{-1} advancing rate drilled to a maximum depth of 30 mm. [49] Bracci *et al* 2008 used the DFMS to measure the effect of barium hydroxide on Gioia marble cut to 5x10x3 and 5x5x3 cm. Measurements were taken to a depth of 10mm using 600 rpm and a penetration rate of 10mm min^{-1}. [50] SINT Technologies reccomends using a 5mm diamond drill bit with a 600rpm rotation speed and a 10mm/min penetrating speed when drilling 10mm holes.These parameters are believed to be typical for many stones and are reccomended when drilling stones of unknown drill resistance.[51]

Despite their wide use in the field, resistance drills have several drawbacks when used on masonry in situ or within the laboratory. Pamplona *et al* 2007 highlighted several possible drawbacks including drill bit variety, wear on the drilling bit, and dust accumulation in the drill hole. Wear accumulation can significantly alter the results and calibration materials must be used at the beginning

[48] De Clercq, H.; and De Zanche, S., "Teos and Time: the Influence of Application Schedules on the Effectiveness of Ethyl Silicate Based Consolidants for Brick", in *Proc. 11th International Congress on Deterioration and Conservation of Stone*, eds. J. W. Lukaszewicx, and P. Niemcewicz (Nicolaus Copernicus University Press, Poland, 2008) 847-856

[49] Ferreira Pinto, A. P.; Delgado Rodriques, J. "The Action of Inorganic Consolidants in Limestones", in *Proc. 11th International Congress on Deterioration and Conservation of Stone*, eds. J. W. Lukaszewicx, and P. Niemcewicz (Nicolaus Copernicus University Press, Poland, 2008) 873-880

[50] Bracci, S.; Matteini, M.; and Sacchi, B. "Development and Evaluation of New Treatments for the Conservation of Outdoor Stone Monuments", in *Proc. 11th International Congress on Deterioration and Conservation of Stone*, eds. J. W. Lukaszewicx, and P. Niemcewicz (Nicolaus Copernicus University Press, Poland, 2008) 819-826.

[51] SINT Technologiy, 2011, *DRMS Cordless MANUAL vers. 3.05*, 28

and at regular intervals during the tool's life span. Pamplona *et al* 2007 also advises that the drill bit should only be used under specific conditions during its lifetime, such as for only one type of stone or experiment. Dust accumulation is of concern as a packing effect is introduced initially as dust accumulated within the drilled hole and increases with drilling depth. [52] In a study conducted by Pinto and Delgado Rodrigues (2008), a 3 mm pilot hole was drilled prior to the drilling test and dust suction was used to enhance the precision of results and avoid dust accumulation.[53]

3.6 RETREATMENT STUDIES

Recently, there has been a greater interest in performing in-situ evaluation of previous treatments. This can easily be explained by the growth of the field of stone conservation during the 20th century and the desire to evaluate the efficacy of previous treatments. However, the reevaluation of previous treatments has highlighted certain difficulties as all the parameters that can cause damage are not known or identified. This is largely due to the fact that conservation documentation from earlier studies does not provide all the necessary data and conservators rarely leave untreated reference surfaces on a monument or structure. [54]

Nevertheless, within the field of conservation, studies on the retreatment of a consolidated stone are rare. Since the arrival of ethyl silicate consolidants in the 1960s, a large number of buildings and monuments initially conserved require further re-treatment and the effectiveness of the first treatment has decreased. Little work had been done on this subject and the effects that one treatment may have on

[52] Pamplona, M; Jocher, M; Snethlage, R; and Barros, L. A. "Drilling Resistance: Overview and Outlook", 669

[53] Ferreira Pinto, A. P.; Delgado Rodriques, J. "The Action of Inorganic Consolidants in Limestones", in *Proc. 11th Int. Conf. on Durability of Building Materials and Components*, eds. J. W. Lukaszewicx, and P. Niemcewicz (Nicolaus Copernicus University Press, Poland, 2008) 873-880

[54] *Ibid.*, 16

another. The nature of a consolidant is to infiltrate a stone and occupy the space between the pores, and subsequent applications of consolidants are more than likely to interact differently than the original application. Nevertheless, re-treatment studies of formerly consolidated surfaces will become more prevalent and important in the next few years.

Ultimately, current research suggests re-treatment of ethyl silicate consolidated stones is possible and can yield good results, but the effects of such re-treatments or the possibility of re-treatment with chemically different consolidants is not well understood.[55] Price and Doehne 2010 have noted the significant swelling of polymers under the influence of solvents, and the hypothesized possible swelling of an original consolidant treatment when a second layer is applied. The second consolidant is also likely to not form a uniform layer over the original, but will likely be an "intermingled mixture."[56] Snethlage 2004 noted that it is possible that sandstone is prone to contour scaling by over-strengthening of the surface. However, his research found that treating sandstones with ethyl silicate products exhibit little to no risk of over-strengthening on the surface zones or the formation of contour scales.[57] Issues such as these highlight the importance of this current study.

[55] Oliver, A. B., 2002, "Variable Performance of Ethyl Silicate Consolidated Stone at Three National Parks," *APT Bulletin,* vol 33. No. 2, 94

[56] Price and Doehne. 2010, *Overview*., 56

[57] Snethlage, Rolf., 2004, "Re-treating Sandstone with Ethyl Silicates- Is There a Risk of Over-Strengthening the Surface" In *Proceedings of the 10th International Congress on Deterioration and Conservation of Stone: Stockholm, June 27-July 2, 2004*
283.

CHAPTER 4: SAMPLE PREPARATION AND TREATMENT

4.1 METHODOLOGY

4.1.1. Identification Of Problem

Comparisons between the 1993 and 2011 photographic conditions assessments of the column in combination with field examination and SEM micrography indicates that the original consolidation was successful in restoring grain to grain cohesion of the disaggregated and flaking stone. Extensive cracking has formed and expanded on various sides of several of the drums. This deterioration is believed to be due to the stone's inherent expansive clays which swell when exposed to water, generating stress and increasing the rate of cracking. Previous analysis and characterization of the stone by Brackin (1993) and Karas (2011) have shown through XRD, petrographic analysis, and microchemical testing that expansive clays are present within the San Antonio Column. The damage has accrued over the last 18 years is likely due to clay expansion compounded by gypsum crystallization from the original mortar and inappropriate previous repairs removed during the initial treatment.

As initially stated by Brackin in 1993, the primary deterioration mechanism of the column drums was the dissolution and recrystallization of gypsum from the original mortar and inappropriate previous repairs, with a secondary mechanism being the swelling of clay minerals inherent within the stone. The decay manifested itself by microcracking, extensive flaking, and disaggregation. The initial treatment with Acryloid B72 and Conservare OH100 addressed the flaking and disaggregations. Over the last 18 years, these conditions addressed in the original treatment program have not manifested again, despite the fact that recommendation to keep the surface hydrophobic through the application of a water

repellent have not been followed. However, the underlying issue of swelling clays not initially addressed has become easier to detect without the interference of salt cycling damage. Currently, it is necessary to propose additional treatment to address this current decay mechanism to prevent further damage to the column.

4.1.2. Identification Of Solutions

Damage created by the expansion of clays is a major problem in the conservation of stone and related masonry materials. Extensive visual and structural deterioration can even occur when the clay percentage within the stone is quite small.[1] Due to the nature of its formation, limestone that is commonly used for building and sculptural purposes often contains a small proportion of clay.[2] Often, in limestone, the clay particles concentrate along the bedding planes, which can lead to separation between individual bedding planes and therefore rapid decay of the stone.

Current research on controlling clay expansion on argillaceous stones indicates the addition of a surfactant can dramatically limit the expansion of the individual clay particles. Snethlage and Wendler showed that treating a stone with $\alpha - \omega$ diamino alkanes greatly reduced inherent clay swelling by reducing the stresses below the tensile strength of the stone. To achieve this, the molecules contain amine groups attached to the end of the alkane chain, which allow for the molecule to bond to adjacent phylosilicate sheets. This compound and other difunctional molecules have been proven effective to control the expansion of clays within Portland Brownstone and resist "washout" after hundreds of wet/dry

[1] Rodriguez-Navarro, C., Hansen, E., Sebastian, E., and Ginell, W.S. 1997. "The Role of Clay in the Decay of Ancient Egyptian Limestone Sculptures," *Journal of the American Institute for Conservation,* Vol 36, No. 2. Pg 151-163

[2] Caner and Seeley 1978

cycles. Jimenez, Gonzalez and Scherer further showed that treatment with several surfactants decreased swelling by increasing the range of molecular sizes in order to fill a range of sizes at the bonding sites.

However, additional research has shown that when this type of compound is combined with a silicate consolidant, the strength and stiffness of the stone is initially increased, but the increase diminishes after several wetting/drying cycles.[3] The cracking of the applied consolidant likely causes the loss of strength during swelling of the clays. The application of an elastified ethyl silicate with surfactant anti-swelling pretreatment has shown to limit expansion of inherent clays while successfully consolidating the stone. Jiménez, González and Scherer further studied this phenomenon by analyzing samples of Portland Brownstone pretreated with a swelling inhibitor and a Conservare® OH-100 treatment. Their results confirmed previous studies and determined a decrease in the static modulus of the stone after 5 wetting/drying cycles.[4]

4.2 SELECTION OF CONSOLIDANTS

The products chosen for this study include the consolidants Conservare® OH100 and Remmers KSE 300E and the anti-swelling agent Remmers Antihygro. Conservare® OH100 has long been used in many consolidation studies since its introduction in the 1990s. Remmers KSE 300 E, an elastified ethyl silicate, is produced in Europe and has become a popular consolidant in the last decade. A relatively new product, Remmers Funcosil® Antihygro, is touted as a treatment for

[3] Wheeler, G., 2005, *Alkoxysilanes and the Consolidation of Stone*. Getty Conservation Institute, 15

[4] Scherer, G.W., and Jiménez González, I. 2007. "Swelling Clays and Salt Crystallization: Damage Mechanisms and the Role of Consolidants," Proc. International Symposium Stone consolidation in cultural heritage, eds. J. Delgado Rodrigues and J. Manuel Mimoso (Laboratório Nacional de Engenharia Civil, Lisbon, 2008). Pg 29-39

"highly swelling capable clayey sandstones with little resistance to weathering."[5]

4.3 SAMPLES

Samples chosen for this project were not sampled directly from the column but from the perimeter wall of the mission. In 1993, San Antonio Missions National Historical Park provided two-inch, saw-cut cube samples from the perimeter wall for the purposes of pretreatment testing for Brackin's research. These samples were similar in color and texture to the column and were weathered but not highly deteriorated. During this initial study, the samples underwent artificial weathering, primarily through salt cycling, in order to replicate the deterioration seen on the column. According to ASTM C88-90, samples were immersed for four hours in a saturated sodium sulfate solution and dried, constituting one cycle. Samples underwent thirteen cycles with minimal deterioration. In order to further induce deterioration, samples were immersed in a 1M sulfuric acid bath for 18 hours and then a bath of 1M hydrochloric acid. At the end of the artificial weathering procedure, it was determined that stones did not reflect the then current conditions at the column, and mortar facsimiles were used instead for Brackin's pretreatment study. The stones, stored for the last 18 years in the Architectural Laboratory at the University of Pennsylvania, were chosen for the purposes of this study as they closely mirrored the composition of the stones within the column and therefore likely contained the same type of swelling clays.

A large boulder taken from the site in 2011 was also transported to the ACL for the purposes of testing drilling resistance. This sample is visually similar to both the samples and limestone within the color and displays the same type of micro-cracking. This sample is a surficial boulder and likely from the same geologic bed as

[5] Remmers, Technical Information Sheet, "Funcosil® Antihygro"

the samples being studied, although this has not been confirmed.

4.3.1 SOURCE OF STONE

Ultimately, it is unlikely that the exact source can be determined without extensive minerologic study. However, it is the purpose of this research to indicate possible locations from which the stone was quarried. The site of the Mission San José Y San Miguel De Aguayo was initially chosen for its close proximity to the materials necessary for building a mission. Lt General Juan Valdes stated that "the land offered rich pastures, plentiful wood for beams, stones for making hearths, and firewood."[6] After the completion of the church in 1777, the building was described by Fr. Juan Agustín Morfi as being "strongly built of stone and mortar, chiefly of a sandy limestone that is light and porous when freshly quarried but in a few days hardens and becomes one with the mortar" and specifically "the stone is obtained from a quarry near the mission of Nuestra Señora de la Concepción." Descriptions of this mission detail that this quarry was known to produce a porous gray rock known as tufa, from which Concepción was constructed. [7]

4.3.2 GEOLOGIC SETTING

Geologically, the mission of the Mission San José y San Miguel de Aguayo and the city of San Antonio lie within the Gulf Coastal Plain physiographic province, consisting of rolling plain and moderate hills. Limestone, marls, sands, and clays largely underlie this area and the local topography often features broad

[6] As quoted in Torres, Luis, *San Antonio Missions National Historical Park,* Southwest Parks and Monuments Association. Tuscon Arizona

[7] *Ibid*, 76

plains with shallow basins formed by the drying and shrinkage of calcareous clays.[8] On the surface, this region is covered by surficial quaternary fluvatile terrace deposits.[9] These deposits occur abundantly throughout the area and conceal much of the underlying geology and structural features within the area. This type of sediment consists of streambed deposits including point bars, cutbanks, and oxbows that are composed of clays, sand, silts, and gravels. Throughout the city, it is likely that the depth and composition of these profiles will differ due to the variable nature of deposition. Below this bed, sedimentary rocks of Cretaceous, Tertiary, and Quaternary age crop out at various locations.[10] Generally these beds dip to the south and southeast within this area.

Table 1 lists the local beds and formations within the area, as determined in 1993 at Lackland Airforce Base located approximately 8 miles away from the Mission. [11] Due to the large number of argillaceous limestone and marls present within the Cretaceous and Tertiary deposits, it is likely that the samples for this study are from this period. During this period, regional uplift caused the sea level to drop throughout central Texas. Cretaceous sediments within Bexar County include calcareous clay deposits to the west and extensive outcrops of Escondido Formation. This formation contains accumulations of flaggy gray calcareous to argillaceous fine-grained sandstones along with thin-bedded orange yellow siltstone, gray shale, and small deposits of sandy marl and limestone. Within the Tertiary system, the deposits represent a period of sea level transgression and are marked by two

[8] Fennerman, N.M., 1938, *Physiography of Eastern United States:* New York, McGraw-Hill, 480 p.

[9] *Geological Atlas of Texas, San Antonio Sheet.*

[10] Ozuna, George B., and Small, T.A. 1993 "Reconaissance Investigation of the Geology and Hydrogeology of Lackland Air Force Base, San Antonio, Texas" *U.S. Geological Survey, Water Resources Investigations Report* 93-4037.

[11] *Ibid,* 4.

Table 4.1: Local Surficial Outcrops of Bexar County

System	Series	Group	Formation	Thickness (ft)	Lithology
Quaternary	Holocene		Fluvatile Terrace Deposits	0 – 25	Gravel, sand, silt and clay.
	Pleistocene		Leona	0 – 26	Calcareous silt grading downward into a coarse gravel
Tertiary or Quaternary	Pliocene or Pleistocene		Uvalde Gravel	5 – 20	Caliche-cemented chert gravel
	Paleocene	Midway	Wills Point	5 – 490	Sandy clay containing sand or limy concretions
			Kincaid	100 – 150	Sand limestone upper part; glauconitic, sandy shale in lower part
Lower Cretaceous	Gulfian	Navarro	Escondido	0 – 30	Calcareous to argillaceous sandstone
			Anacacho	135 - 200	Calcareous clay and fossiliferous mudstone
		Eagle Ford Group	Eagle Ford	15 – 30	Interbedded, laminated calcareous mudrock
	Comanche	Washita Group	Buda	40 - 56	Glauconitic crystalline limestone
			Del Rio	15 - 50	Gypsiferous and calcareous clay with minor calcareous siltstone

formations, the lower Kincaid Formation and the overlying Wills Point Formation. Kincaid Formation is marked by impure glauconitic limestone with abundant pyrite nodules. The later Wills Point Formation also contains sandy clays that weather to a golden brown, similar to those found in the Escondido Formation. [12]

Due to the large number of argillaceous limestone and marls present within the Cretaceous and Tertiary deposits, it is likely that the samples for this study are from this period. Specifically it is like that the stone was quarried from either the Escondido or Wills Point Formations. However, due to the variability of these deposits within Bexar County, it is difficult to determine the exact formation from

[12] Sellards, E. H., 1919.*The Geology and Mineral Resources of Bexar County,* University of Texas Bulletin. No. 1932., 119

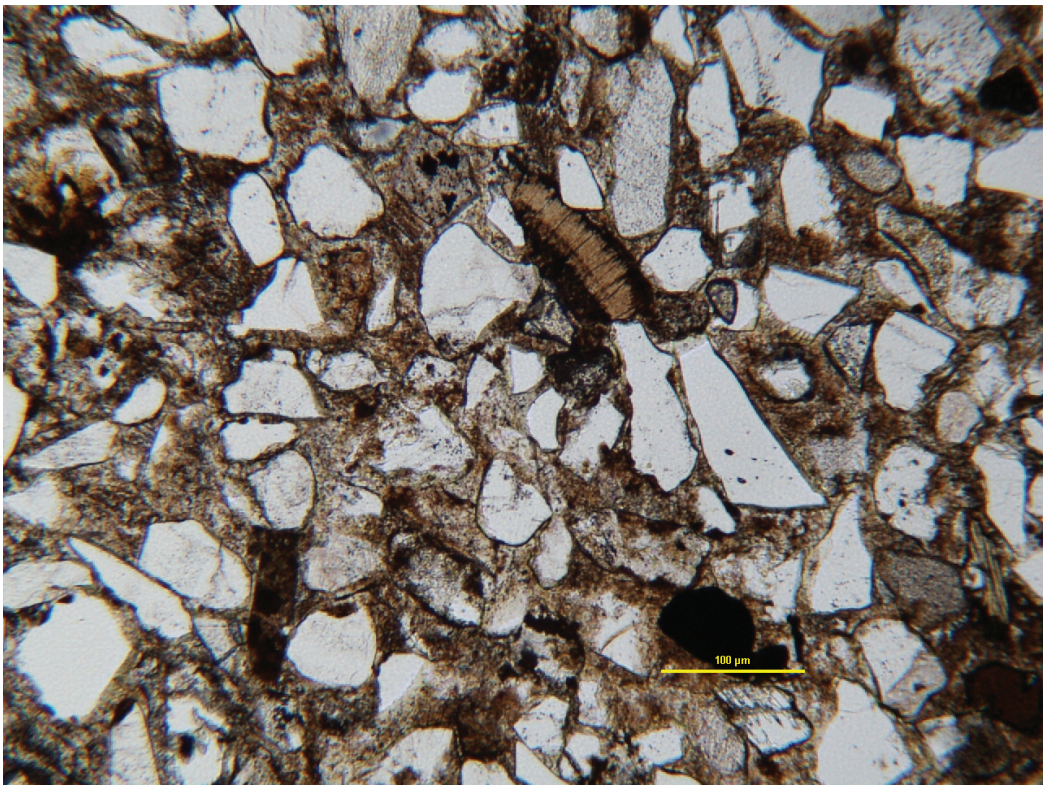


Figure 4.1 San Antonio Perimeter Sample in plane polarized light under 100x magnification

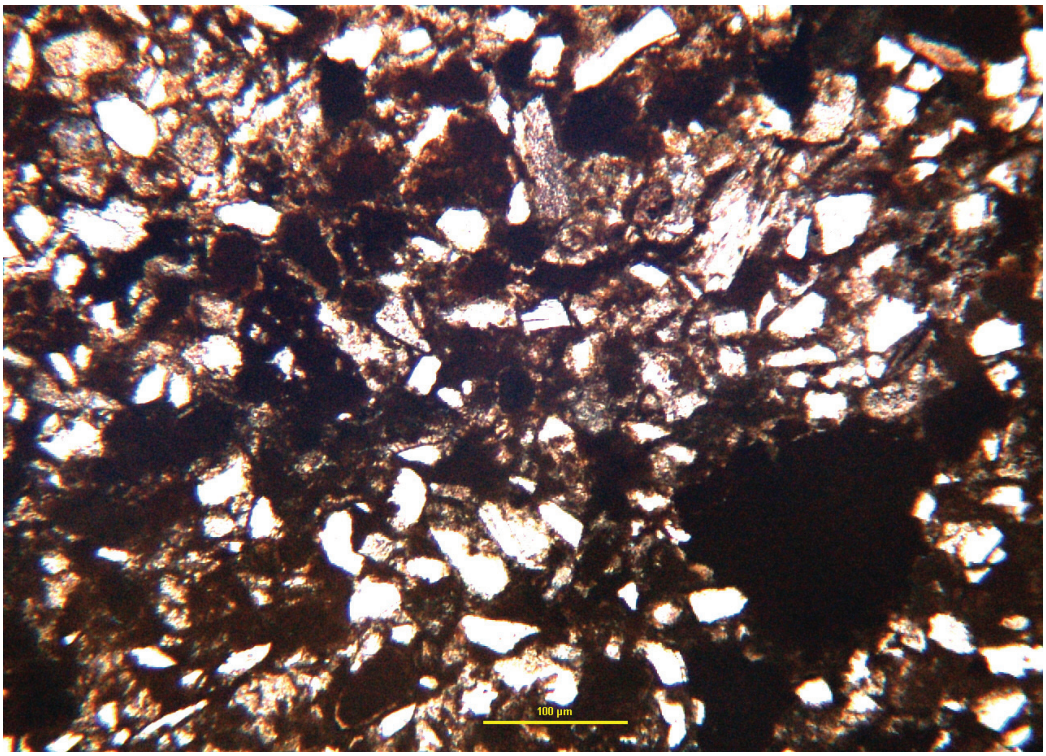


Figure 4.2 San Antonio Column sample in visible light under 100x magnification

which these stones originated.[13]

4.3.3 PETROGRAPHIC ANALYSIS OF SAMPLES

In order to confirm that perimeter wall stones were geologically similar to the stone that composes the column, thin sections were made from the samples available and a petrographic analysis was undertaken. These samples were compared with thin sections previously created from samples taken from both the upper and lower portions of the column drums prior to treatment in 1993.

Two thin sections were made per sample and a sample from each was dyed in either a blue or clear epoxy. The blue epoxy allows for an easy visual understanding of the porosity of the stone.

[13] Reprinted from Ozuna, George B., and Small, T.A. 1993 "Reconaissance Investigation of the Geology and Hydrogeology of Lackland Air Force Base, San Antonio, Texas" *U.S. Geological Survey, Water Resources Investigations Report* pg 4.

As illustrated by the images taken, the facsimile perimeter samples contain a significantly smaller proportion of clays. However, is it apparent in both thin sections that the stones are composed of angular quartz grains sand embedded in a cryptocrystalline calcite matrix. Under polarized light, the large proportion of clays sized particles “clouded” the calcite crystals within the cementing matrix. The orange to brown color within the matrix is due to the presence of goethite (FeO(OH), a common iron oxide mineral that forms as a result of the weathering of other ferrous minerals.

Despite the visual similarity between the two stones in hand sample, it is apparent that the testing stones have significantly larger quartz grains than observed within the stones sampled directly from the column. However, both samples contain relatively impure and angular grains, indicating the sediment did not travel far prior to initial deposition. Gypsum crusts were also visible within the sample stone and were similar to those seen on the column. A greater proportion of feldspar crystals were also seen within the testing stones, but the porosity, indicated by the presence of blue voids within the stained thin sections, is similar among the samples.

Ultimately, through petrographic analysis it is obvious that the testing stones differ from the column stones several significant areas including quartz grain size, frequency of feldspar crystals, and proportion of clays. Therefore,it is necessary to note that the testing stones may not behave in the same manner as the stones within the drums of the column, but have been confirmed to be similar in composition and can act as facsimiles.

4.3.4 DIVISION OF AVAILABLE SAMPLES

The total number of samples used for treatment included 28 cubes, 12 coupons, and a surficial boulder. The samples were divided as follows:

DETAILED SAMPLE LIST					
Sample ID	**Sample Location**	**Type**	**Date Sampled**	**Sampled by**	**Consolidant**
A1.1	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.2	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.3	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.4	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.5	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.6	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.7	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A1.8	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Control
A2.1	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	Control
A2.2	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	Control
A2.3	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	Control
B1.1	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.2	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.3	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.4	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.5	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.6	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.7	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B1.8	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	KSE 300 E
B2.1	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	KSE 300 E
B2.2	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	KSE 300 E
B2.3	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	KSE 300 E

Table 4.2a Detailed Sample List

DETAILED SAMPLE LIST					
Sample ID	**Sample Location**	**Type**	**Date Sampled**	**Sampled by**	**Consolidant**
C1.1	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.2	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.3	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.4	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.5	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.6	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.7	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C1.8	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C2.1	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C2.2	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	Antihygro + KSE 300E
C2.3	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	Antihygro + KSE 300E
D1.1	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.2	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.3	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.4	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.5	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.6	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.7	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D1.8	Perimeter Wall	2” X 2” X 2” Cube	1993	A. Brackin	OH100
D2.1	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	OH100
D2.2	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	OH100
D2.3	Perimeter Wall	2” X 2” X 0.2” Cube	1993	A. Brackin	OH100
E1.1	Surficial Boulder	Boulder	2011	F. Matero	Control
E1.2	Surficial Boulder	Boulder	2011	F. Matero	KSE 300E
E1.3	Surficial Boulder	Boulder	2011	F. Matero	Antihygro + KSE 300E
E1.4	Surficial Boulder	Boulder	2011	F. Matero	OH100

Table 4.2b Detailed Sample List

4.4 PREPARATION OF SAMPLES FOR TREATMENT

Prior to treatment samples were washed with deionized water and brushed clean of any surface salt deposits with a natural bristle brush. Samples were then dried in an oven at 60°C and removed when the samples achieved a constant mass. The large boulder had been treated with D2 prior to consolidant application to remove algal growth on the surface of the stone. Due to its size and mass, the boulder was not weighed or dried. It has remained indoors at ambient temperatures

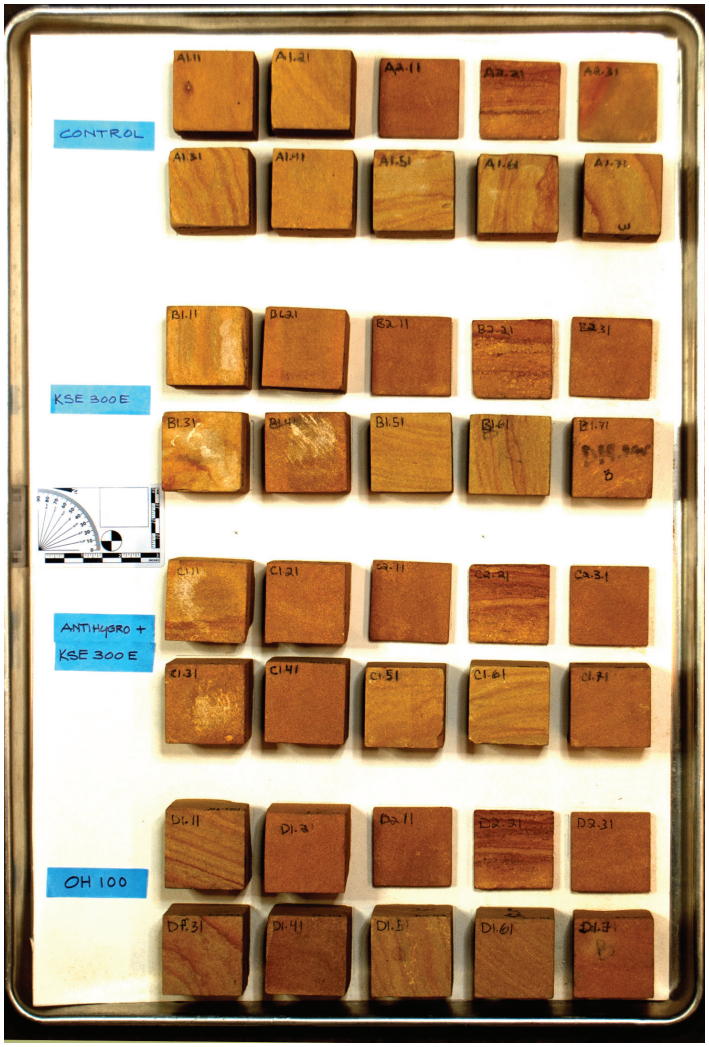


Figure 4.4 Samples A to D Prior to Treatment

for 5 months.

4.5 APPLICATION OF TREATMENTS

Samples were then divided into their respective cohorts comprised of seven 2” cubes and three 0.5” x 10” square coupon . A total of four cohorts (control, Conservare® OH100, KSE 300 E, and Funcosil® Antihygro® + KSE 300 E) were identified with twenty-eight 2” cubes and twelve 0.5” coupons. All stones were labeled on all faces with a marker to denote cohort (letter), sample within cohort (number), and face of sample (number).

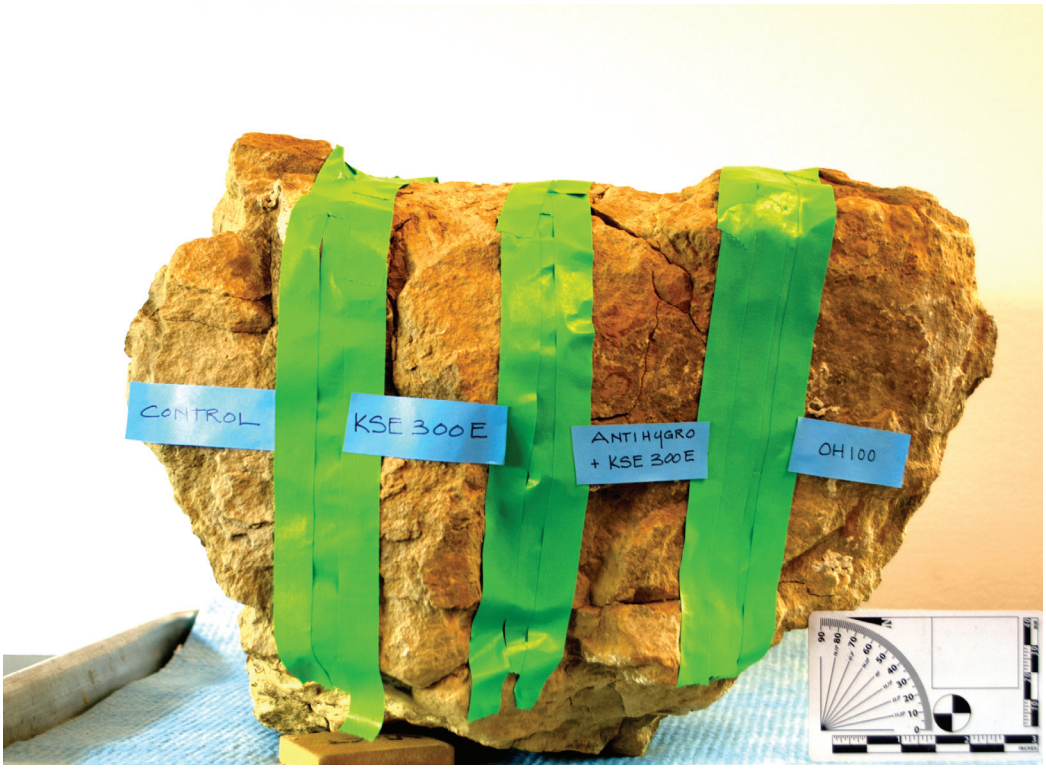


Figure 4.3 Boulder Sample E Prior to Treatment

4.5.1 APPLICATION OF ANTI-SWELLING AGENT.

Pretreatment Application of Funcosil® Antihygro

One cohort of samples was treated with an anti-swelling agent prior to consolidation. The method of application was driven by the manufacturer's recommendations and the application methods of similar treatment studies. A 2" natural bristle brush was used to apply the consolidant to the surface of the stone. The brush was dipped within the treatment and applied to the surface of each stone using two quick and even strokes in order to saturate the stone. Following this application, the same method was used to apply the anti-swelling agent to the same face of each sample within the cohort. After 15 minutes, the process continued with two more applications and finished the first cycle. The samples were then left to sit for 30 minutes in order to determine if there was refusal on the surface.

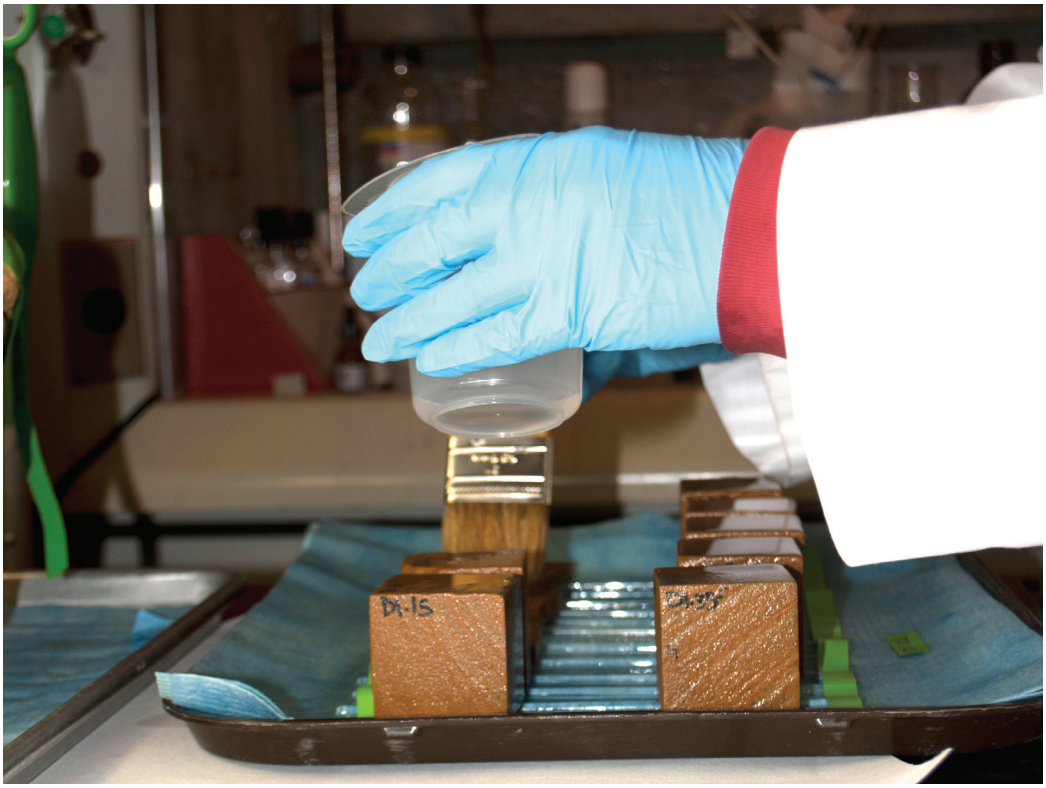


Figure 4.4 Application of OH100

If further treatments were required, another cycle would then be applied. When refusal was apparent, the samples were turned to the following numbered face and the application cycle was repeated until refusal on that face. This entire process continued until 5 faces of each sample were treated at least once and the bottom was left untreated in order to preserve an untreated face on the stone. However, following application that it became apparent that this face was fully consolidated despite not being brushed due to the low viscosity of all the consolidants.

Samples treated with Antihygro were left to cure overnight in the fume hood and then moved to a tented baker's rack. These samples were cured approximately a total of 9 days in the baker's rack before being applied with the KSE 300 E consolidant.

4.5.2 APPLICATION OF CONSOLIDANTS

Application of Conservare® OH100

Conservare ® OH100 was applied to one cohort of samples. The same method of application was used to apply OH100 as was used to apply the Antihygro pretreatment. However, due to a lack of pooling on the surface, the top and initial surface of each sample was applied with 5 cycles of consolidant prior to applications on other sides. Due to the aforementioned lack of refusal, it was decided during application that the porosity of the stone allowed excess consolidant to quickly move through the sample, and that at least one cycle of application on each side would ensure adequate consolidation. To support this theory, the mass of each sample was recorded after each cycle and application stopped when the mass remained the same.

Following application, the sample surface was flashed with methyl ethyl ketone as recommended by the manufacturer and an absorbent pad was used to

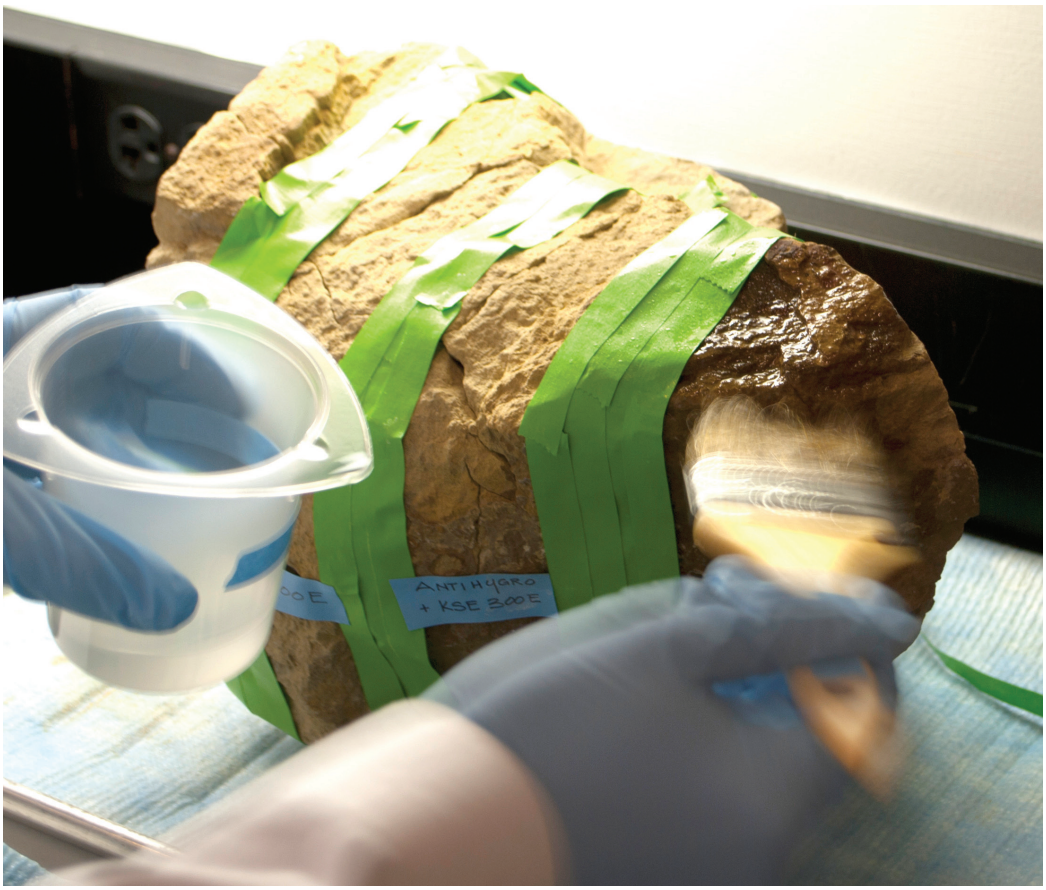


Figure 4.5 Application of Consolidant to Boulder

remove excess consolidant and avoid a change of color and a change in the surface texture caused by cured consolidant on the surface of the stone.

Application of Remmers KSE 300 E.

Remmers KSE 300 E was applied to two separate cohorts of samples, one untreated cohort and another that had been pretreated with Funcosil® Antihygro. The same process was used to apply KSE 300 E as OH100 with the exception that the top face of each sample underwent three cycles of application prior to the treatment of other faces. The apparent refusal on the surface of each sample was greater than that experienced with OH100, but did not remain for 30 minutes as recommended by the manufacturer, likely due to the porosity of the San Antonio

limestone being treated.

4.6 CURING OF SAMPLES

Following treatment, samples were stored overnight in the fume hood for the solvents to evaporate. The following day, the samples were placed on a tray and stored in a tented baker's rack within the laboratory. Samples were left to cure for 52 days. Initially cure time was planned to be 30 days but it was decided to extend cure time to allow for as much time as possible for the consolidants to fully react and cure**.** Temperature and relative humidity were monitored through the use of an Onset HOBO data logger. The temperatures ranged from 63° F to 74° F and the relative humidity ranged from 13% to 61%. Despite the samples being placed within a tented baker's rack, it is apparent that the samples were exposed to the fluctuations in temperature and especially relative humidity within the conservation laboratory.

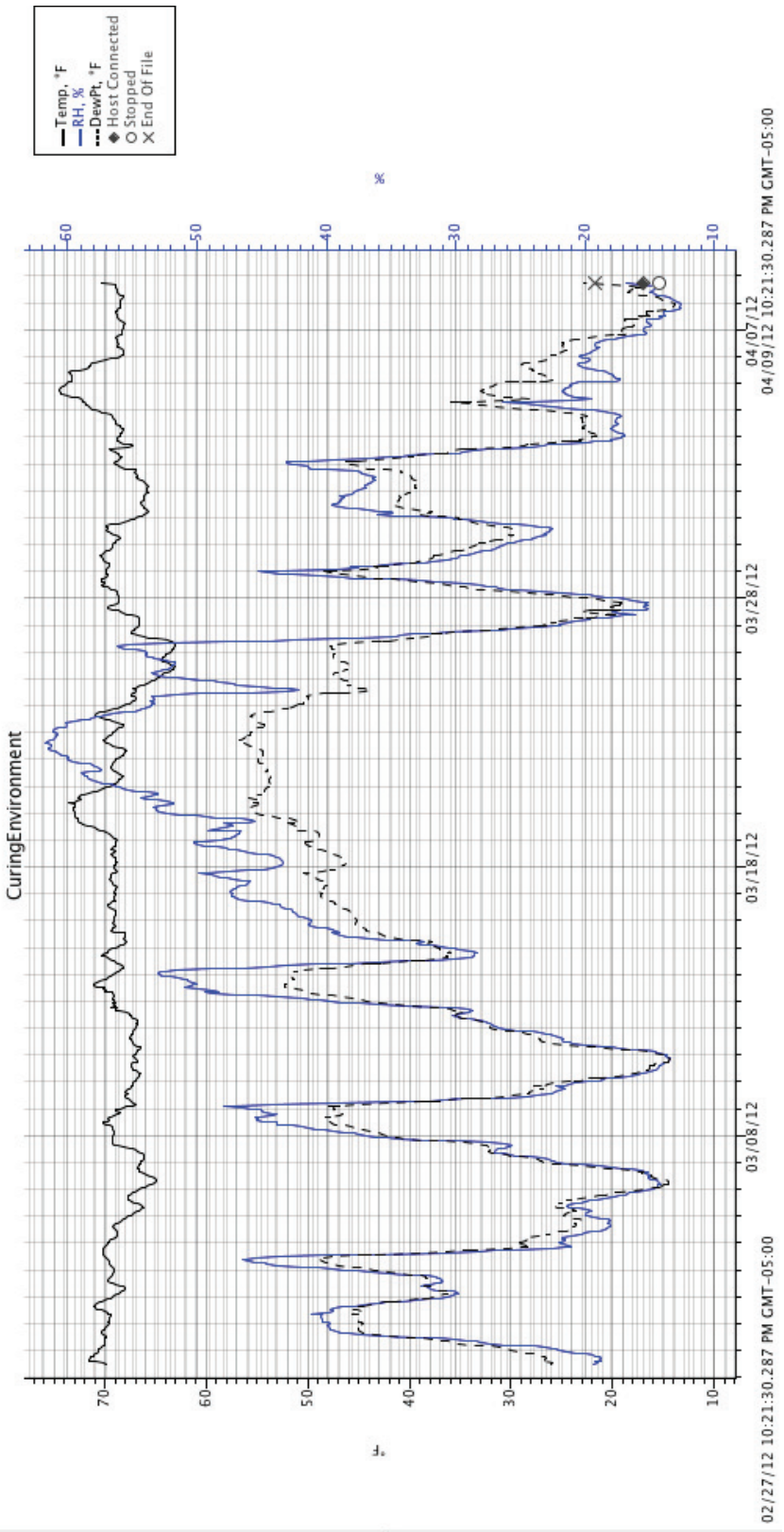


Figure 4.6: Graph produced by datalogger showing temperature, relative humidity, and calculated dew point during curing.

CHAPTER 5: EXPERIMENTAL PROGRAM

5.1 TESTING PROGRAM

An overall testing methodology was established in order to understand the physico-mechanical changes in the properties of the consolidated stone. The desired properties to be measured during testing are those properties considered essential or critical to consolidation. They include compatibility and durability testing as well as characterization varying from depth of penetration, vapor transmission, color change, and liquid water absorption and drying.

SAMPLE SCHEDULE						
Test Method	**Reference**	**Sample Dimensions**	**Sample Shape**	**Number of Groups**	**Samples per Variable** (*Cohorts*)	**Total Samples per Test**
SOLUBLE SALT ANALYSIS	As determined by Dr. A.E.Charola	2g piece	VARIABLE	1	1	1
COLOR	ASTM D1535	2" X 2" X 0.2"	VARIABLE	Samples from WVP	Samples from WVP	Samples from WVP
CAPILLARY ABSORPTION	ASTM C67-97 and ASTM C948-94	2" X 2" X 2"	CUBE	4	3	12
DRYING INDEX	NORMAL 29/88	2" X 2" X 2"	CUBE	Samples from Capillary Absorption	Samples from Capillary Absorption	Samples from Capillary Absorption
WATER VAPOR PERMEABILITY	ASTM E96/ NORMAL 21/85	2" X 2" X 0.2"	SQUARE	4	3	12
XRD (Destructive)	**LRSM Guidelines**	**Variable**	**N/A**	**Samples from WVP**	**Samples from WVP**	**Samples from WVP**
DRILLING RESISTANCE (Destructive)	**LOTZMANN AND SASSE 1999**	**2" X 2" X 2"**	**CUBE**	**Boulder Sample**	**Boulder Sample**	**Boulder Sample**
SEM (Destructive)	**KARAS 2011**	**Variable**	**N/A**	**Samples from Column**	**Samples from Column**	**Samples from Column**

Note: BOLD = DESTRUCTIVE

Table 5.1 Sample Schedule. Note: Bold indicates a destructive test.

5.2 QUANTIFICATION OF SOLUBLE SALTS

Semi-quantitative chemical strips were used to quantify the concentrations of soluble salts present in the original untreated samples. EM Quant strips were used specifically for this purpose and the samples were tested for the following salts: sulfates, nitrates, nitrites, and chlorides.

5.2.1 Methodology

Samples used for salt testing included: untreated yellow limestone sampled from the lower portion of the column, a grey limestone sampled from the capital, and a sample from an untreated cube from the perimeter wall. The samples were dried at 60° C in a lab oven until a constant mass was obtained. A 2.00g sample was taken from each cube for the purposes of the semi-quantitative analysis and further dried until a true dry weight could be calculated. The samples were then pulverized using a ceramic mortar and pestle and then placed in a pre-weighed beaker where approximately 100mL of distilled water was added. The solution was then stirred using a magnetic stir plate and bar, then left to sit for two hours to settle. The suspension was then filtered using a piece of previously weighed filter paper into another flask and reserved for later testing. The filter paper retaining the aggregate was dried overnight, cooled to room temperature, and dried until the mass remained constant.

5.2.3 Calculations

The % relative moisture content of each sample was calculated as follows:

$$\% \text{ Relative moisture content (w/w)} = [(w_{h+s} - w_{h+d})/ w_d] * 100$$

Where: w_{h+s} = the weight of the sample and container

w_{h+d} = the weight of the dry sample and container

w_d = the weight of the dry sample

The *% Relative Soluble Salt Content* was determined by the equation:

$$\% \text{ Relative Soluble Salt content (w/w)} = [(w_d – w_{g+p+des} – w_p – w_g)/ w_{gd}]*100$$

Where: $w_{g+p+des}$ = the weight of the extracted salt sample on filter paper and container

W_p = the weight of the filter paper

w_g = the weight of the watch glass

w_{gd} = the weight of the dry extracted sample

The soluble salt concentrated in g/L was determined by:

$$\text{Salt Concentration [g/l]} = [(w_d – w_{g+p+des} – w_p – w_g)/V_{soln}] * 1000 \text{ ml/l}$$

where: V_{soln} = the final volume of the salt solution after filtering.

Semi quantitative analysis

Commercial ion strips were used for the purposes of this test. The expiration

date and lot numbers were recorded to ensure that the strips were active. Using a pipette, drops of the filtered solution which was set aside during the previous step were placed upon each ion strip, timed, and monitored as specified. The strips developed according to the technical data provided. A color change usually indicated a particular concentration of salts in solution. From this data, the relative anion concentrations were calculated.

The relative anion concentration was determined as follows:

Ion (g/g) % = [Strip Reading (mg/l)*V_{soln} (l) x 100] / [w_d (g)_ 1000 mg/g]

5.3 COLOR CHANGE

Color change was measured according to ASTM D 1535 – 80 "Standard Method of Specifying Color by the Munsell System" in order to determine if any of the consolidation treatments affected the color of the samples.

5.3.1 Methodology

Color change was measured through visual comparison between treated and untreated samples using the Munsell color identification system in natural northern daylight. Describe Munsell in one sentence. Four samples were analyzed including an untreated control, sample treated with OH100, a sample only treated with KSE 300 E, and a sample with the combined Antihygro pretreatment and KSE 300 E. For each sample, the stone was compared to the Munsell colors until a color match was found. The *hue value/chroma* of the Munsell color match was recorded.

5.4 CAPILLARY ABSORPTION

Capillary absorption tests were based primarily on a combination of standards including NORMAL 11/85, 7/81, and 29/88; ASTM C67-97 and ASTM C948-94, ARC Laboratory Handbook, ICCROM 1999. This test was undertaken in order to measure the changes in capillary water absorption of treated and untreated samples in order to determine if there is a difference in absorption rates from the application of the different consolidation treatments. Ultimately, any changes in the water absorption of a stone caused by a conservation treatment may impart a measure of water repellency and may reduce the potential for deterioration.

5.4.1 Methodology

Capillary absorption tests were performed on three 2-inch cubes from each cohort. Samples were oven-dried at 60° C and their respective masses were recorded after drying to room temperature. Samples were then placed within a plastic container with a tight fitting lid on a thin sponge cloth. Deionized water was added to the container in order to allow the sponge to remain saturated. The samples were then placed onto the saturated sponge, and the time was recorded from this point. Samples were weighed every 5 minutes for the first hour, then every 30 minutes for the next hour. Following this, samples were weighed every hour for the next 2 hours and then hourly until the water absorption stabilized. When readings were taken, the samples were individually removed from the container, patted try with a damp paper towel and placed on the balance. After the mass was recorded, the samples were returned to the container and the lid was placed on the container, sealing the chamber to prevent evaporation. Once the samples reached the asymptotical water absorption value, the samples were left in the container for 24 hours before a final measurement was taken.

5.4.2 Calculations

Following testing, capillary water absorption curve plots graphing the amount of water absorbed per unit surface M_I (g/cm^2) over the square root of time. The capillary absorption coefficient was determined by measuring the slope of the initial straight portion of the curve.

Following immersion, the imbibition capacity was determined by the ratio of

$$[Wmax - Wdry] / Wdry$$

5.5 DRYING INDEX

Drying index tests were based primarily on a combination of standards including NORMAL 11/85, 7/81, and 29/88; ASTM C67-97 and ASTM C948-94; ARC Laboratory Handbook, ICCROM 1999. This test was performed to understand the drying behavior of the control and treated stones after being saturated during the capillary absorption test.

5.5.1 Methodology

The drying index test was performed immediately after the test for capillary absorption was complete. Samples were removed from the container and left to dry on a balance for 30 minutes, with the mass being recorded every 3 minutes during the first 15 minutes. Once the initial rapid drying had stopped, the samples were then placed on a drying rack in a draft-free environment. Readings were then taken every 10 minutes for the first hour, followed by every 15 minutes for the next hour, and then every 30 minutes for the next 2 hours. Following this period of time, readings were taken hourly until the asymptotical value was determined by plotting the drying curve.

5.5.2 Calculations

The moisture content (Ψ) was determined as follows:

$$(\Psi = (Ut/Vol_{sample}) \ (g/cm3).$$

Where: U_t = the water content

Vol_{sample} = The total volume of the sample

Following testing, the drying rate of the stone was plotted against time.

5.6 WATER VAPOR PERMEABILITY

Water vapor transmission tests were performed according to ASTM E96-90 “Standard Test Methods for Water Vapor Transmission of Materials” using the water method outlined in the standard. The purpose of this test is to measure and determine any significant changes in the water vapor transmission rates caused by the application of the three individual treatments.

The water vapor transmission properties of the stone are extremely important in the moisture management and durability of the exterior of a building or structure, especially if the stone has been treated. Ultimately, the direction and degree through which water vapor moves through an exterior surface or wall is due in part to climactic gradients and also the nature of the material through which it passes. Following a period of saturation, a majority of the moisture within a material will leave the system as water vapor through evaporation. Transmission will be greater in highly porous material, which allows moisture to pass through the material and potentially deteriorate more rapidly through salt crystallization or freeze thaw cycling. Significant changes in water vapor transmission rates caused by the application of a consolidant can have significant negative effects by inducing and accelerating deterioration.

Samples chosen for this test were 2-inch square coupons with a thickness of 0.2 inches that were cut from a cube during the original study in 1993. The samples were not cored in a circular disks as it was thought that this would likely crack and/or destroy the sample. Therefore, a new testing apparatus had to be constructed.

5.6.1 Sample Dish Construction

A special dish was fabricated for the purposes of this experiment comprised of a square glass container capped by an acrylic top. The acrylic top was laser cut at

the School of Design Fabrication Lab at the University of Pennsylvania and cut to allow for a 2-inch square to hold the sample and allow proper vapor transmission. The acrylic top was adhered to the glass container by 3M-silicone sealant in order to thoroughly seal the edges and left to cure for 24 hours, per manufacturer's recommendation.

The test dish was filled with approximately 50mL of distilled water. Cotton balls were placed within the container to reduce condensation within the sealed container, which could theoretically alter water vapor transmission rates. Samples were wrapped three times in Scotch Super 33+ ¾ inch electrical tape to seal the edges of the sample and prevent transmission of vapor through the sides of the samples. The samples were then placed on the top of the container. Heated paraffin wax was applied with a Pasteur pipette to hold the sample and hermetically seal the

Figure 5.1 Test Dish Construction

Figure 5.2 Assembled Cubes ready for testing

edges of each specimen in order to create an appropriate assembly for the test.

5.6.2 Methodology

The ASTM standard E96-90 was modified slightly during the initial phase of testing to dry the stone samples prior to mounting on the test assembly. This was done to maintain consistency across the entire testing program. Samples were dried in an oven at 60° C until the mass remained constant and the difference between two repeat weighings was less than or equal to 0.01% of the initial weight of the sample. The test assembly was weighed initially and then placed into a controlled climatic chamber with a hygrometer to achieve and maintain a constant temperature of 20°C and a relative humidity of 50%. Initially, samples were weighed at elapsed times of 5, 15, 30, and 60 minutes. Samples were weighed periodically henceforth, and daily following in order to create sufficient data points. Testing finished when the recorded mass did not change over several days.

CHAPTER 5: EXPERIMENTAL PROGRAM

The water vapor transmission of the samples measured were determined as follows:

$$WVT = G/tA = (G/t)/A$$

where: G = weight change (from straight line), g,

t = time, h,

G/t = slope of the straight line, g/h,

A = test area (sample area), cm^2, and

WVT = rate of water vapor transmission, g/h cm^2

Permeance of the stones were calculated by the following formula:

$$Permeance = WVT/S\ (R_1 - R_2)$$

where: S = saturation vapor pressure at test temperature, mm Hg (1.333 x 102 Pa)

R1 = relative humidity at the source expressed as a fraction (100% in the dish for water method)

R2 = relative humidity at vapor sink expressed as a fraction (in the chamber for water method).

From this value, average permeability was calculated by:

Average Permeability= Permeance x Thickness

5.7 DEPTH OF PENETRATION WITH DRMS SYSTEM

Drilling resistance was used in order to determine durability of the stone samples. This test is intended to measure the depth of penetration of a calibrated drill through stone by the continuous measurement of the force needed to drill a hole into a stone material. In the case of this thesis, resistance drilling was used to determine statistically significant differences of penetration depths between treatments and a control (untreated stone). The three separate brush-applied treatments consisted of Prosoco® OH100, Remmers® KSE 300 E, and Remmers® Antihygro + KSE 300E. This test is pivotal in this research as it is considered one of the best methods for evaluation of the strength increase post-consolidation of soft stones.

5.7.1 Methodology

A large, irregular, boulder obtained from the site by Frank Matero in 2011 was previously treated in three separate areas with the three separate consolidation treatments plus an untreated control. A DRMS cordless drill manufactured by SINT Technology and prepared by Alessio Benincasa was specifically used for the drilling test. For the purposes of this study, a 3 mm diamond Diaber drill bit was used with the following parameters: 600 rpm (rotation speed), and a 10 mm/min (advancing rate) to a depth of 30 mm. DRMS-Cordless 3.05 software, provided by SINT Technology was used to run the equipment and analyze testing data through the use of a small lap top.

Five drill holes were made for each treated section of the boulder. The data from each formulation and a control. The same test parameters were applied to 2” cube repair stone facsimiles. One set of data was measured on dry stones. A set was measured by drilling the wet stone after 24 hours of immersion in deionized water.

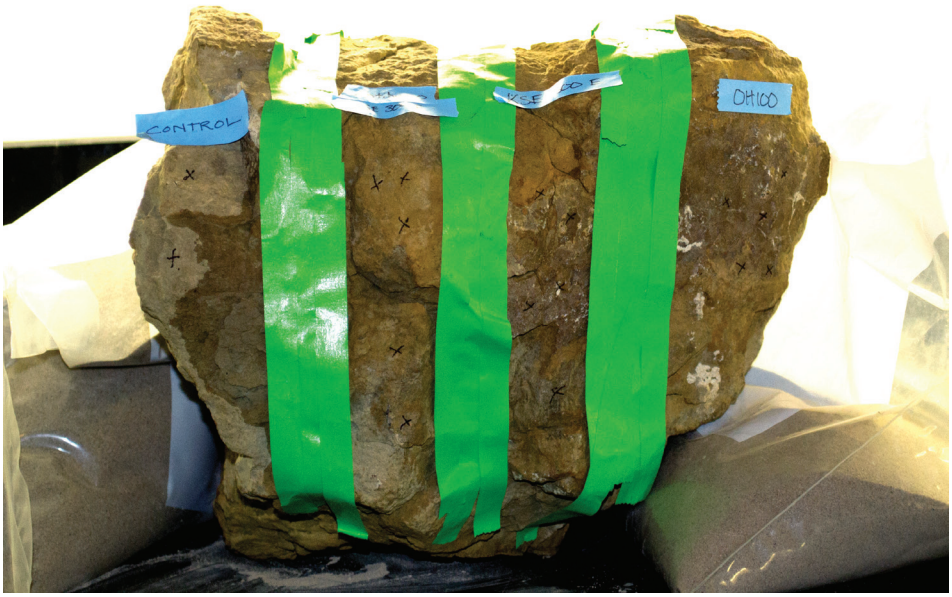


Figure 5.3 Bulk sample prior to Drilling

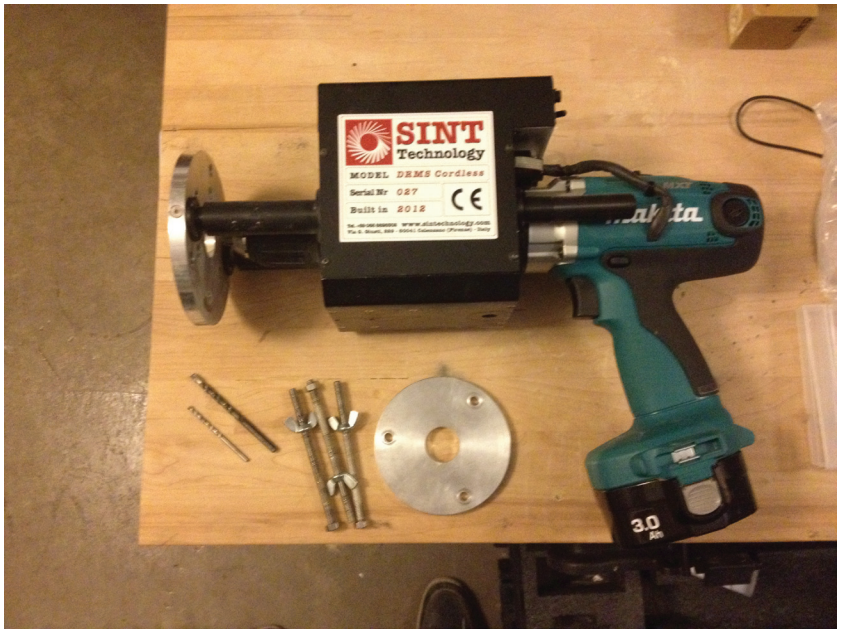


Figure 5.4 DRMS Cordless System produced by SINT Technology with drill bits and attachments

5.8 SEM ANALYSIS

Scanning electron microscopy (SEM) was performed on a selected sample at the Winterthur Museum Scientific Research and Analysis Laboratory by Catherine Matsen. Prior to analysis, a sample was selected from a delaminated piece of stone sampled directly from the column by Frank Matero in 2011. The site was specifically chosen for SEM analysis as it was believed that the delamination was primarily caused by clay swelling and expansion, and therefore it was likely that distressed and expanded clay grains could be seen in this location.

5.8.1 Methodology

The sample intended for analysis, approximately 0.5 - 1.0 mm^2 in diameter were mounted facing up to a carbon stub with double-sided carbon tape adhesive. The stone samples were carbon coated under vacuum in an SPI-Module Carbon Coater. This procedure reduces the surface charges on the sample by evenly distributing a carbon coating, which creates a conducting layer. This layer allows the sample to be better imaged in a scanning electron microscope.

The samples were placed inside the Topcon ABT-60 scanning electron microscope at an accelerating voltage of 11 kV, stage height of 22 mm, and sample tilt of 20°. The scanning electron microscope uses electron beams to create analytical data by two lenses and an electron field emission gun. With a normal optical glass lens, photons of light are passed through the lens as wave energy. In a SEM, physical bodies are passed through an imaginary lens, which is actually a magnetic field in the shape of a lens through which electrons pass. The use of accelerated electrons instead of light allows for higher resolution than can be attained through the use of an optical microscope.

A very small field emission gun within the SEM creates the identical

electrons, which then hit the sample and produce secondary electrons. The electrons that do not bounce off the sample are known as backscatter electrons and are more prominent in the presence of atoms with large nuclei.

The backscatter image helps produce a “topographic” image of the sample. Through the use of the detector within the SEM, additional images can be created using the backscatter and secondary electrons. Secondary electron images (SEI) were captured with Bruker Esprit 1.8 software. On this imaging software, the brighter spots produced on the backscatter image illustrate the heavier elements while the dark spots display areas of little information and lighter elements. When understanding the relationship between voltage and spot size on the sample, the highest voltage uses the smallest spot size. Samples that are not excellent conductors require the initial use of lower voltages progressing slowly to higher voltages.

Figure 5.5 K. McNabb operating opcon ABT-60 scanning electron microscope

5.9 X-RAY DIFFRACTION

5.9.1 Methodology

Sample preparation for powder XRD analysis was performed according to a procedure outlined in Milton's *X-ray Diffraction and the Identification and Analysis of Clay Minerals* (1997). A sample of the limestone from the perimeter wall sample was ground to powder in ceramic mortar and pestle. Care was taken to prevent the over-grinding of quartz grains in the samples. The powder was then sieved through a U.S. Standard sieve stack with an additional #400 sieve (38 μm) at the bottom to refine the clay size particles. This is performed with the intention of isolating a fraction of the sample to more clearly identify the smaller clay particles.

The samples were then taken for x-ray diffraction analysis and were placed as a powder within an aluminum sample holder. Preparation was done in this method to ensure that powder samples obtained were smooth, flat, and mineralogically similar.

The samples were then taken to the MSE Undergraduate Laboratory XRD Facility at the University of Pennsylvania and analyzed on a Rigaku Powder Diffractometer by Steven Szewczyk at the School of Sciences and Engineering. Samples were analyzed on a 2-theta/theta reflection with a starting angle approximately 15° and an ending angle at 60°. The scan speed used for analysis was 2 °/min with a sampling interval 0.05 ° at a voltage of 45kV and current of 30mA. Data created during analysis was analyzed using the program X'Pert HighScore Plus.

CHAPTER 6: EXPERIMENTAL PROGRAM OBSERVATIONS

6.1 QUANTIFICATION OF SOLUBLE SALTS

Calculation of Soluble Salts			
Parameter	Yellow Column Sample	Grey Column Sample	Yellow Perimeter Wall Sample
Relative Soluble Salt Content (%) (w/w)	2.263±0.20	2.20±0.20	2.14±0.20
Relative Soluble Salt Content (%) (w/w) (Confirmation Test)	3.23±0.20	2.30±0.02	2.99±0.02
Final Salt Concentration (mg/L)	1.45±0.17	1.10±0.17	1.45±0.17

Table 6.1: Recorded data from soluble salt analysis showing the relative soluble salt content determined by two methods and the final calculated soluble salt concentration.

Semiquantitative Analysis of Anions Present In Sample					
Parameter	Brand	Sensitivity (mg/L of Anion	Strip Reading (mg/L) Yellow Column Sample	Strip Reading (mg/L) Grey Column Sample	Strip Reading (mg/L) Yellow Wall Sample
Ion (g/g) % SO4^2-	EM Quant ©	Up to 1600mg/L	400.00	200.00	200.00
Ion (g/g) % Cl-	HACH QuantLab	Up to 6742mg/L	0.00	0.00	0.00
Ion (g/g) % NO2-	HACH Aquacheck	Up to 50mg/L	0.00	0.00	0.00
Ion (g/g) % NO3-	HACH Aquacheck	Up to 3.0mg/L	5.00	1.00	1.00

Table 6.2 Concentration of salts present within samples determined by Semiquanititative Analysis

6.1.1 Discussion

The findings from this test are in agreement with those previously performed by Brackin (93') and Karas (2011'). Semi-quantitiative analysis performed on the samples taken directly from the column indicates that the stone contains a salt concentration of approximately 1.45±0.17 g/L and a sulphate (SO^{2-}_4) concentration of 400mg/L. Brackin determined in 1993 before treatment that the stone contained sulphate concentrations of approximately 240mg/L. A small amount of nitrates (NO_3^{2-}) up to 0.5mg/L were also found during her analysis and are similar in comparison to the 10mg/L found during this study. The difference in slight sulfate concentrations between these two studies indicates the continued presence of gypsum within the column, can be attributed to the presence of gypsiferous mortar within the column. Despite previous and successful efforts to poultice the column to remove these salts, small concentrations will always exist within the stone.

6.2 COLOR CHANGE

Figure 6.1 Samples following treatment and curing arranged to indicate color change. (A) Untreated (B) KSE 300 E (C) KSE 300 E + Antihygro (D) OH100

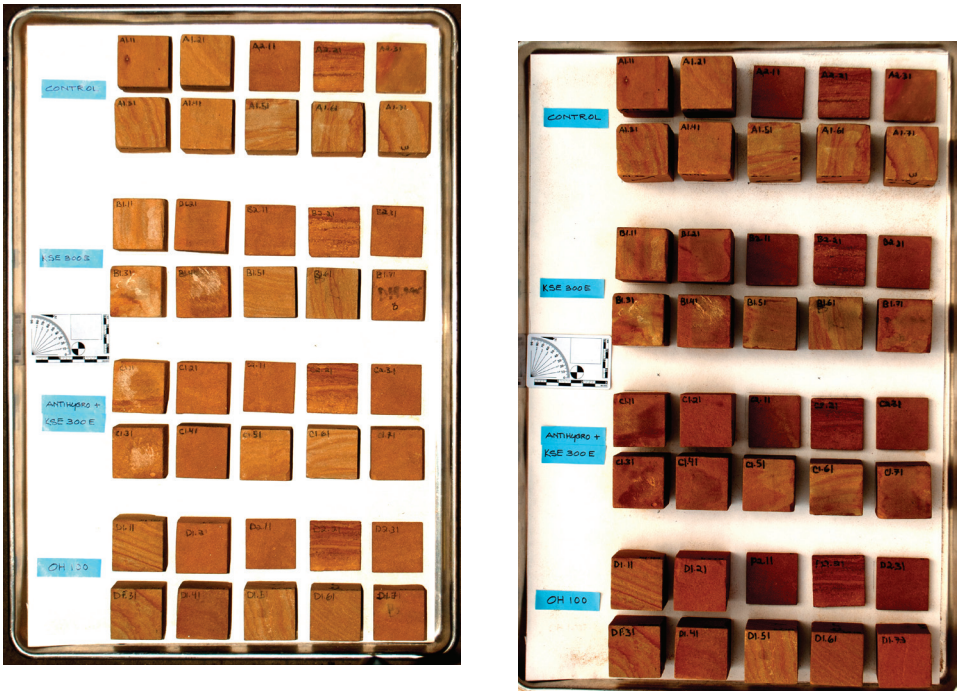


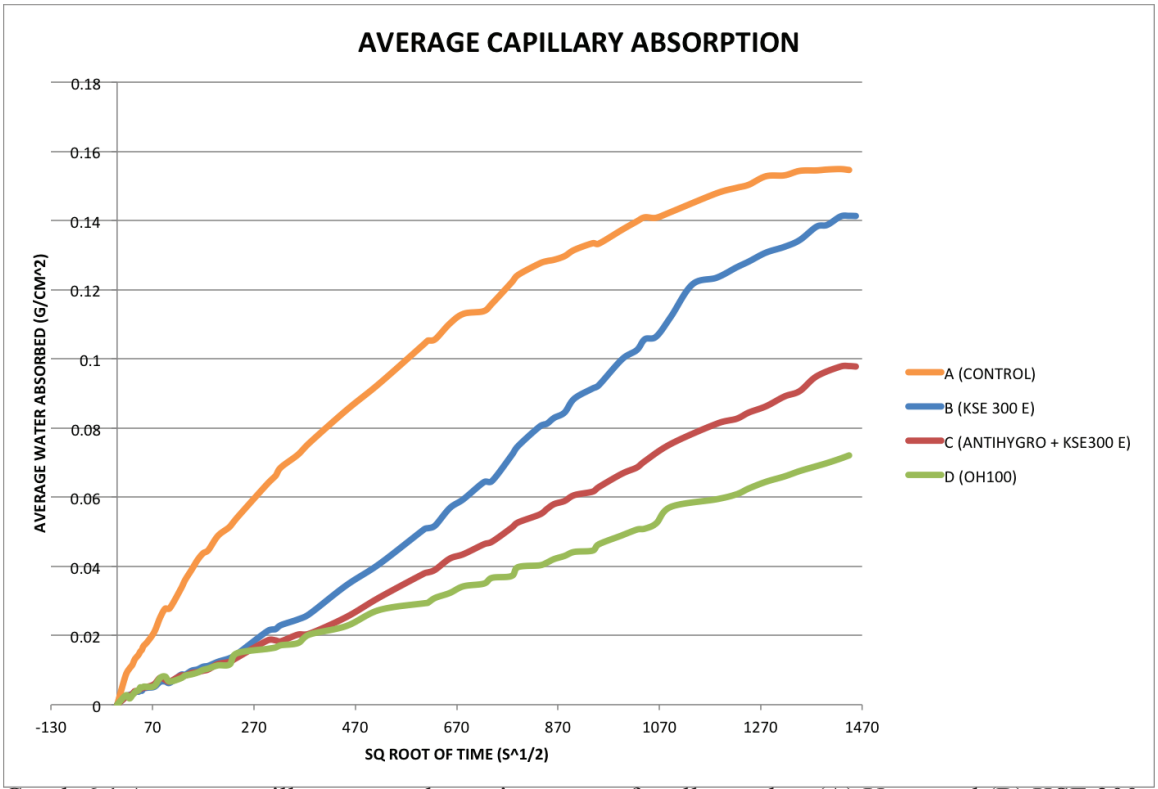
Figure 6.2 All samples before treatment (left) and following treatment (right)

Discussion

Samples selected from each cohort were analyzed using the Munsell Color system. Samples from cohorts A, B, and C, which included both untreated samples and those treated with KSE 300 E had a Munsell color of Hue 10YR 7/6 “Yellow” and 10 YR 6/6 “Brown Yellow”. This variation in color is due to the natural

variation in the sediments that comprise the limestone. Samples D, initially treated with OH100 were matched to 10YR 7/8 “Yellow” and 10YR 6/8 “Brownish Yellow.” This result would suggest a slight shift in chroma caused by the treatment of OH100 to the stone. Therefore, OH100 was determined to be the only treatment to have an impact on color, as no visible color change was recorded in samples treated with KSE 300 E and Antihygro after 51 days. Specifically, between samples B and C, there appears to be no color change with the pretreatment of Funcosil® Antihygro and application of KSE 300 E.

6.3 CAPILLARY ABSORPTION

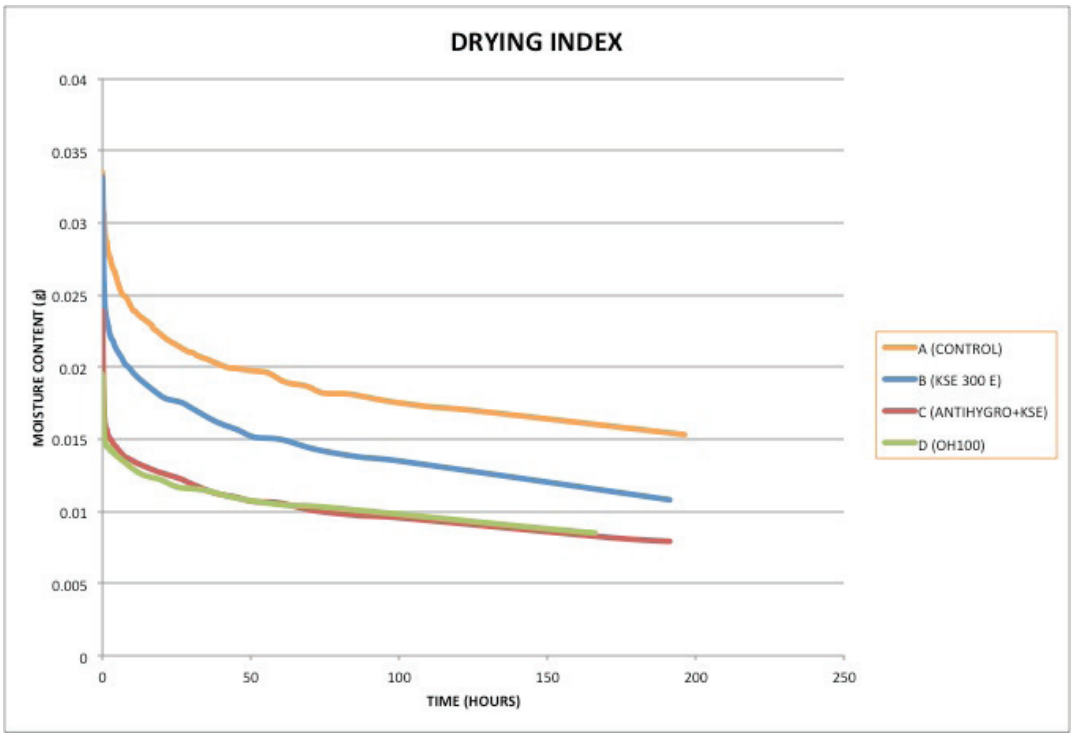


Graph 6.1 Average capillary water absorption curves for all samples. (A) Untreated (B) KSE 300 E (C) KSE 300 E + Antihygro (D) OH100

6.3.1 Discussion

The test for capillary absorption lasted approximately one month. Overall, all samples display a relatively slow rate of capillary absorption, primarily caused by the low porosity of the stone. As expected, the untreated sample had the highest rate of capillary absorption. Sample D (OH100) had the lowest rate of capillary absorption. It appears the addition of an anti-swelling agent in sample C (KSE 300 E + Antihygro) further reduced the capillary absorption of the stone treated with KSE 300 E. It is likely that the surfactant within the treatment prevented the hygroscopic expansion of the clays, reducing absorption. Samples treated with only KSE 300 E (group C) showed a parabolic increase in capillary absorption that was not seen in any other sample.

6.4 DRYING INDEX



Graph 6.2 Average drying index curves for all samples (A) Untreated (B) KSE 300 E (C) KSE 300 E + Antihygro (D) OH100

6.4.1 Discussion

The drying rate took approximately one week to perform. All samples were shown to have similar drying rates. Overall, sample D (OH100) was seen to have the slowest total drying rate while sample B (KSE 300 E) had the lowest initial rate of the treated samples. Sample C (Antihygro + KSE 300 E) behaved the most similarly to sample D possibly due to the fact that the anti-swelling treatment prevented hygroscopic absorption during total immersion that allowed the water within the stone to evaporate at a faster rate.

6.5 WATER VAPOR TRANSMISSION

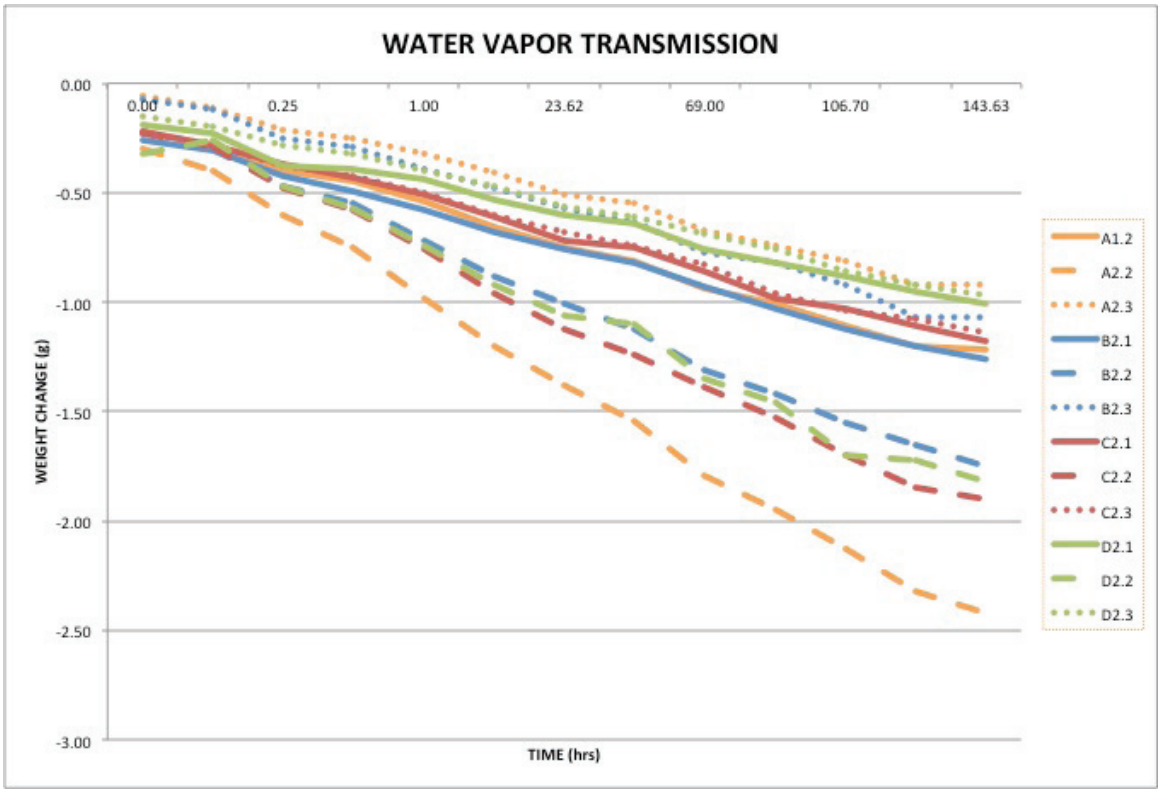
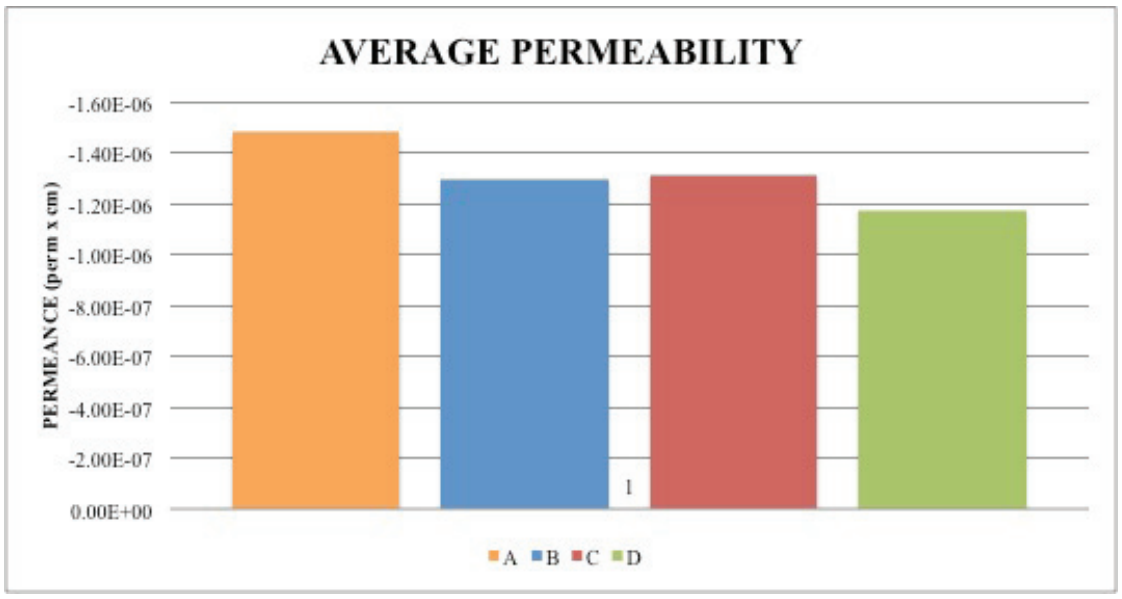


Figure 6.3 Water Vapor Transmission graphs for all samples. (A) Untreated (B) KSE 300 E (C) KSE 300 E + Antihygro (D) OH100

6.5.1 Discussion

Water vapor transmission testing continued for approximately 13 days with the testing chamber having an average temperature of 25.6°C and a relative humidity of 49.2% RH, well within the guidelines mandated by ASTM E96-10.

As seen above in Figure 6.3, the water vapor transmission rate was set at a fixed decline after an initial period of equilibrium. A clear straight line that fits the plot of approximately six lines is visible (Figure 6.3) The slope of this line, as stated in ASTM E96-10, can be approximated as the water vapor transmission rate for each respective sample. The testing data for this test can be seen in Appendix B.



Graph 6.4

WATER VAPOR TRANSMISSION CALCULATIONS						
SAMPLE	WVT (G/H·M2)	AVG WVT (G/H·M2)	PERMEANCE (G/PA·S·M2)	AVG PERMEANCE (G/PA·S·M2)	PERMEABILITY (PERM·CM)	AVG PERMEABILITY (PERM·CM)
A2.1	-1.49		-2.20E-04		-1.12E-06	
A2.2	-3.15	-1.97	-4.65E-04	-2.92E-04	-2.36E-06	-1.48E-06
A2.3	-1.29		-1.90E-04		-9.66E-07	
B2.1	-1.45		-2.15E-04		-1.09E-06	
B2.2	-2.25	-1.73	-3.32E-04	-2.55E-04	-1.69E-06	-1.29E-06
B2.3	-1.47		-2.18E-04		-1.11E-06	
C2.1	-1.39		-2.05E-04		-1.04E-06	
C2.2	-2.51	-1.75	-3.70E-04	-2.58E-04	-1.88E-06	-1.31E-06
C2.3	-1.34		-1.98E-04		-1.01E-06	
D2.1	-1.16		-1.71E-04		-8.71E-07	
D2.2	-2.34	-1.57	-3.46E-04	-2.31E-04	-1.76E-06	-1.17E-06
D2.3	-1.19		-1.76E-04		-8.93E-07	

Table 6.3 Indicating calculated WVT rate, permeance, and permeability.

CHAPTER 6: EXPERIMENTAL PROGRAM OBSERVATIONS

The testing area of the samples was 4 in^2 (0.00258 m^2) with a sample thickness of 0.2 inches (0.0051 m). The recorded average relative humidity of the chamber was 49.2% RH and the humidity within the test chamber was 100%. From these values and the measured data, the water vapor transmission rate, permeance, and permeability of each sample were determined and are presented in table 6.4. Averages for each sample group have also been calculated to aid in the discussion of the results.

Table 6.4 indicates that the all the treated samples had lower water vapor transmission rates than the untreated control. Sample group D, treated with OH100, had the lowest average values recorded during testing with a permeance of -2.31^{E-4}. Sample groups B and C, treated with KSE 300 E and Antihygro + KSE 300 E had similar values, at -2.55 E^{-04} and -2.58 E^{-04}, respectively. This indicates that the anti-swelling pretreatment does not significantly affect the water vapor transmission rates. The unique behavior of every third sample within each cohort, as evidenced by the dashed line on Figure 6.3, is possibly due to the orientation of the beds within the individual scans. Visual inspection confirms that these samples were parallel to the bedding structure, unlike the other samples within the same testing group. This orientation allowed water vapor to more quickly pass through the stone.

6.6 DEPTH OF PENETRATION WITH DRMS SYSTEM

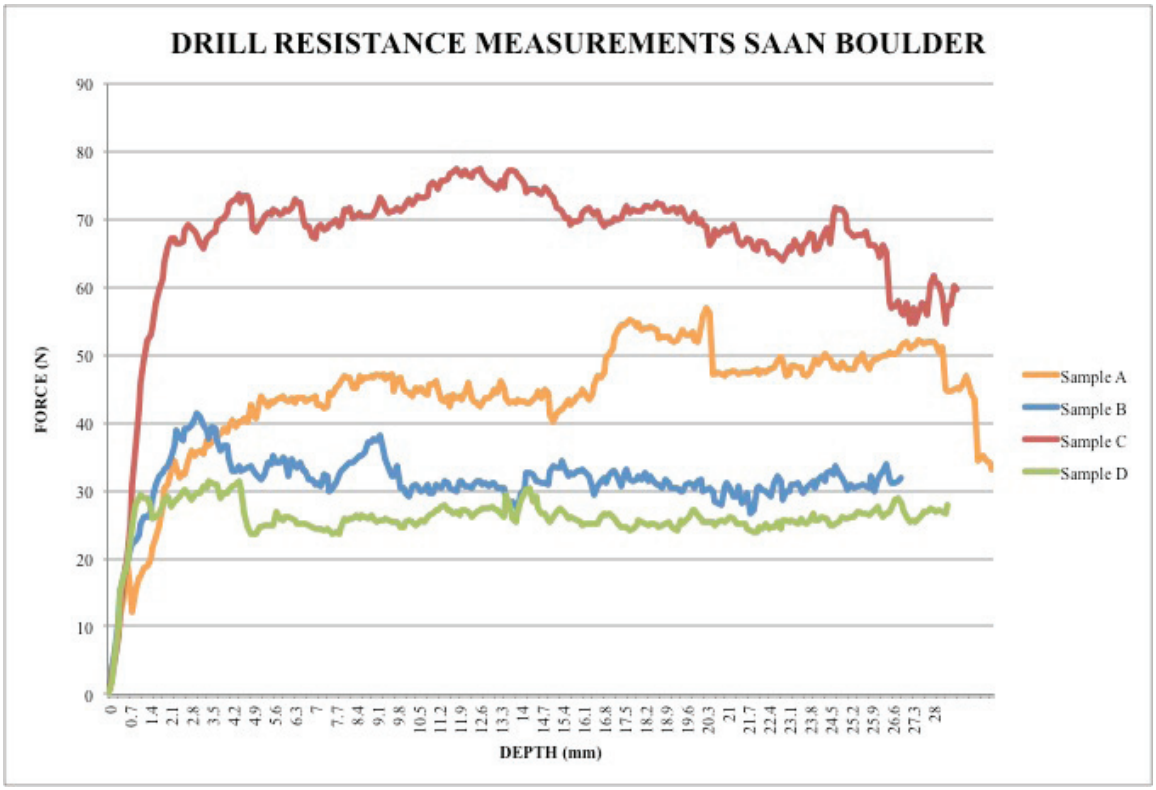


Figure 6.5 Drilling measurements taken on large boulder.

6.6.1 Discussion

Drill resistance measurements performed on the bulk sample were taken under the following parameters: 30mm depth, 10mm/min advancing rate, and 600rpm with a 3mm drill bit. These parameters were initially chosen as they were recommended by SINT Technology for limestone and sandstone substrates. A 5mm drill bit was initially used as recommended by the company, but this caused a cell overload during each drilling test. A 3mm drill bit was able to adequately penetrate the stone but testing was subsequently limited to a max drill depth of 30mm. Sand bags were used to stabilize the stone during drilling.

Each sample area on the bulk specimen was drilled approximately 5 times in order to obtain an representative drill resistance profile. One 2-inch cube from each cohort was also selected to be drilled in order to determine the strength imparted by

each consolidant on a fully consolidated sample.

DRMS-Cordless 3.05 software was used to analyze the data and create an average profile for each area of treatment. This data was then transferred to Microsoft Excel and graphed.

As evidenced in measurements taken directly from the boulder, the Antihygro (Treatment C) and KSE 300 E (Treatment D) imparted the greatest increase in drill resistance of the treatment. Treatments B and C were shown to have similar resistance profiles within the stone. An initial increase in strength in the first 4mm can be seen in all treatments, compared to the untreated stone, most likely a direct effect of consolidation. Resistance profiles taken from the control area of the stone were shown to have a higher strength than both Treatments B and D. This may be due to the inherent compositional variability within the stone or a possible error in application of the OH100 and KSE 300 E consolidants.

Cube samples were initially drilled using the same parameters for the drilling resistance test on the bulk specimen. The control (untreated stone) was able to be drilled successfully to 30mm using the same parameters to allow for comparisons between the measurements taken on the stone. Drilling measurement were not able to be performed to 30mm on the treated stones B,C, and D as the drilling resistance was greater that could be determined by the DRMS using the same parameters. In order to obtain a reading, each stone was drilled at 1000rpm with a 3mm/min advancing rate and a 3mm drill bit, a testing configuration recommended for marbles and granites. Despite this change, readings were only able to be taken to a certain depth in each stone as evidence in Figure 6.6.

According to these measurements, it is apparent the consolidation increased the strength of the stone. However, the exact depth to which the consolidant affected can not be determined as it did not fully penetrate through the sample. New research

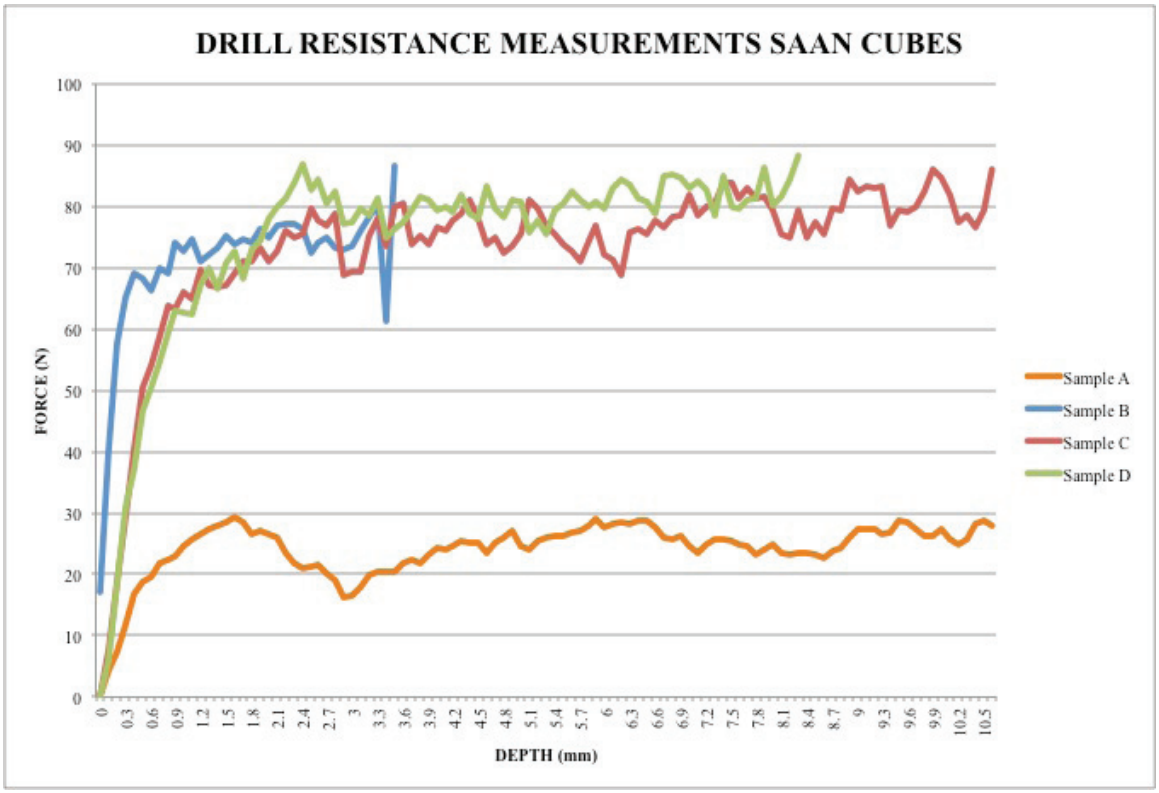


Figure 6.7 Performing DRMS test on sample cube

has shown that the use of hollow diamond coring bits has been successful on exceptional hard materials.[1]

6.6.2 Sources of Error

There are several significant errors that could have affected the accuracy of this test. When drilling on the large bulk specimen, it was common for the drill to bounce and vibrate upon initial contact, causing the drill to move slightly and the recorded force to vary. Any slight movement of the drill would affect the reading taken by the load cell, skewing the data, which was especially difficult when low advancing rates were used. During several occurrences, the drill bit did not

[1] Mimoso J., Costa D. 2008. A new technique for using DRMS in hard materials. Application to the study of the consolidation action. In: Delgado Rodrigues & Mimoso (Eds.) *Proceedings of the International Symposium for Stone consolidation in cultural heritage – research and practice*, LNEC, Lisbon, pp. 359-368

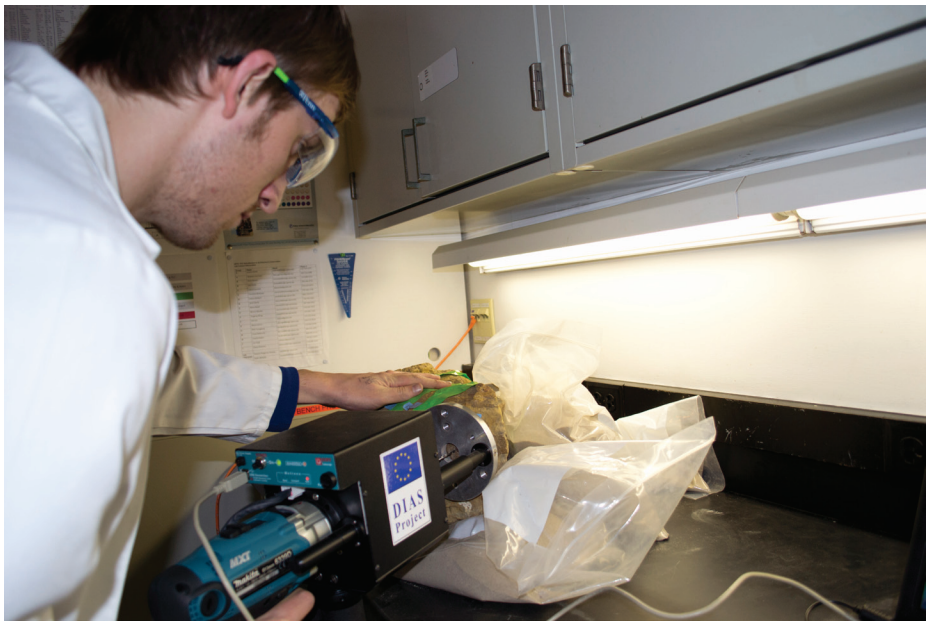


Figure 6.3 Performing DRMS test on boulder.

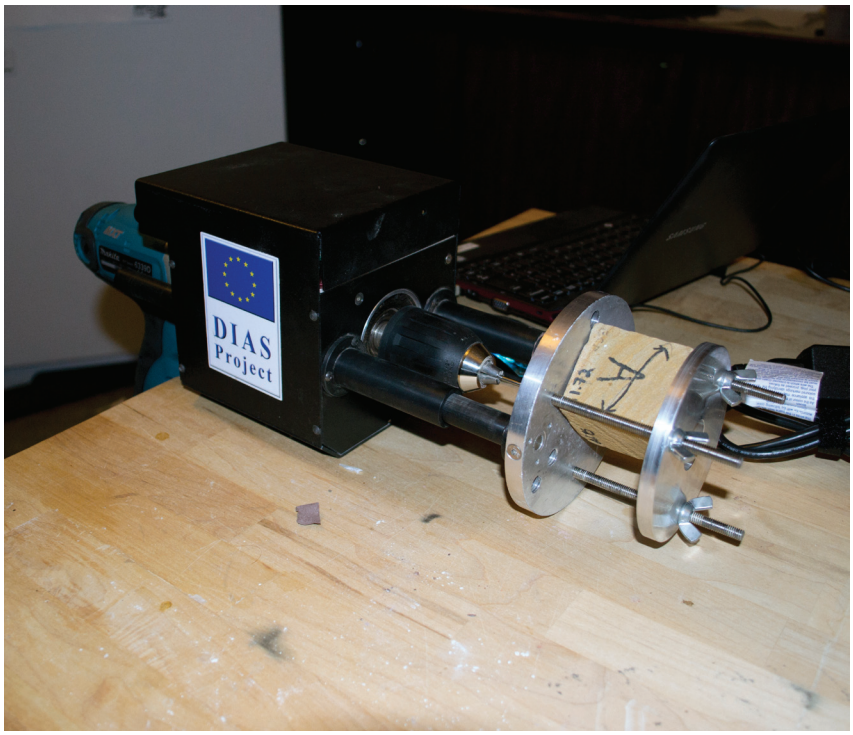


Figure 6.4 Performing DRMS test on sample cube

easily penetrate the stone despite adequate pressure being applied to the surface. The application of greater pressure on the drill and stone surface was avoided, as this commonly overloaded the load cell and ended the test prematurely. Proper technique and operation of the drill requires extensive training and experience as the successful operation of this drill requires a steady pressure to insert the bit and keep the drill straight yet a light enough hand to apply enough pressure without skewing the data. Due to these constraints, it appears that this testing is much more successful and reliable when used on hand samples that can be placed within the mount on the drill.

6.7 SEM ANALYSIS

6.7.1 Discussion

Scanning electron microscopy confirmed the presence of MTMOS polymers as previously found by Karas in 2011. Within these samples and images, MTMOS water repellent treatment applied to the column is identified by elastic polymer strands that bridge the gaps between particles within the stone. Karas previously discussed the difficulty in differentiating between the B-72 polymers and MTMOS polymers under the SEM, as the characteristic cracking of ethyl silicates was not immediately seen. [1]

The treated sample analyzed for this study showed several polymer strands

[1] Karas, N., 2011, "Evaluation of the 1993 Conservation Treatment of the San Jose Convento Column San Antonio Missions National Historic Park, San Antonio, Texas", Graduate Thesis, Univ. Pennsylvania, 65-69.

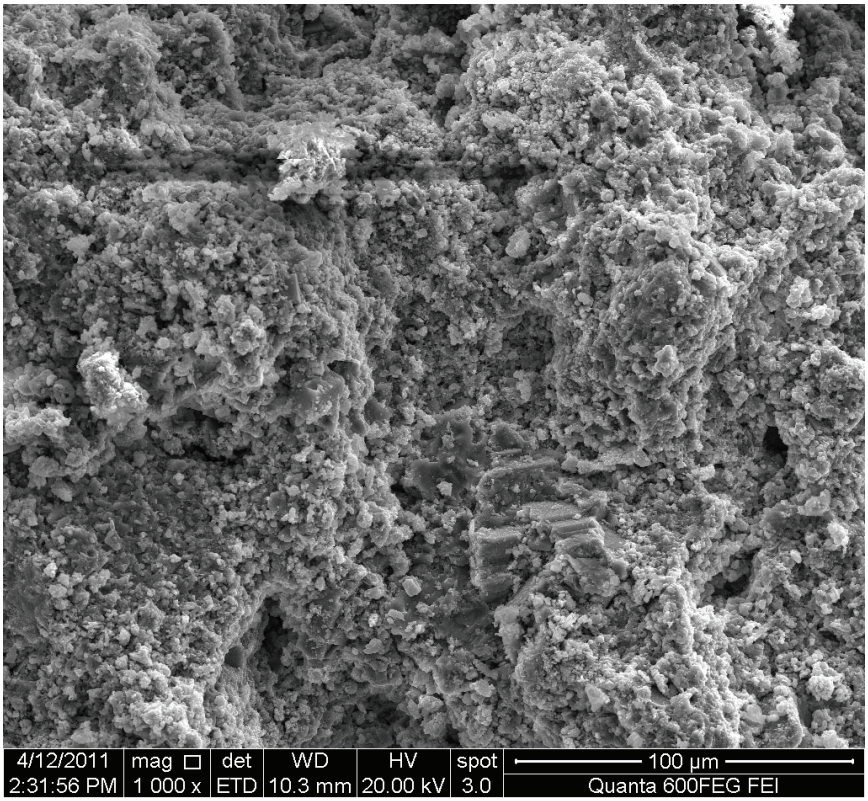


Figure 6.5 Untreated sample taken from the column (Karas 2011)

and localized areas of the signature ethyl silicate cracking. The findings were in agreement with Karas' assumption that the consolidant had not fully cured when the MTMOS water repellent was applied, causing the two treatments to react and act as a mixture after application.

SEM analysis did not find an area within the sample where expanded clay particles were distinctly visible. Due to machine limitations, high magnification used by Karas was not possible. Within these samples, the consolidant MTMOS mix was seen to coat many of the crystals within the sample and characteristic strands

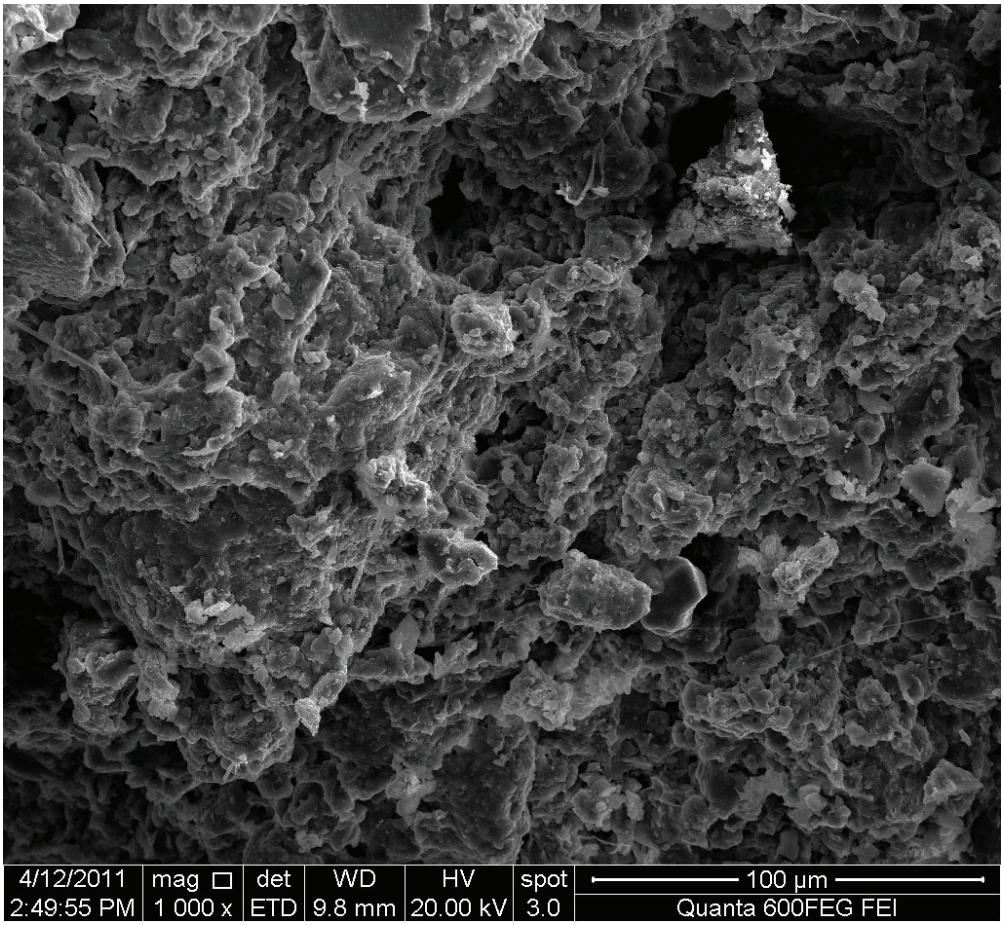


Figure 6.6 Treated sample of San Antonio Limestone from north column face, drum #3 (Karas 2011)

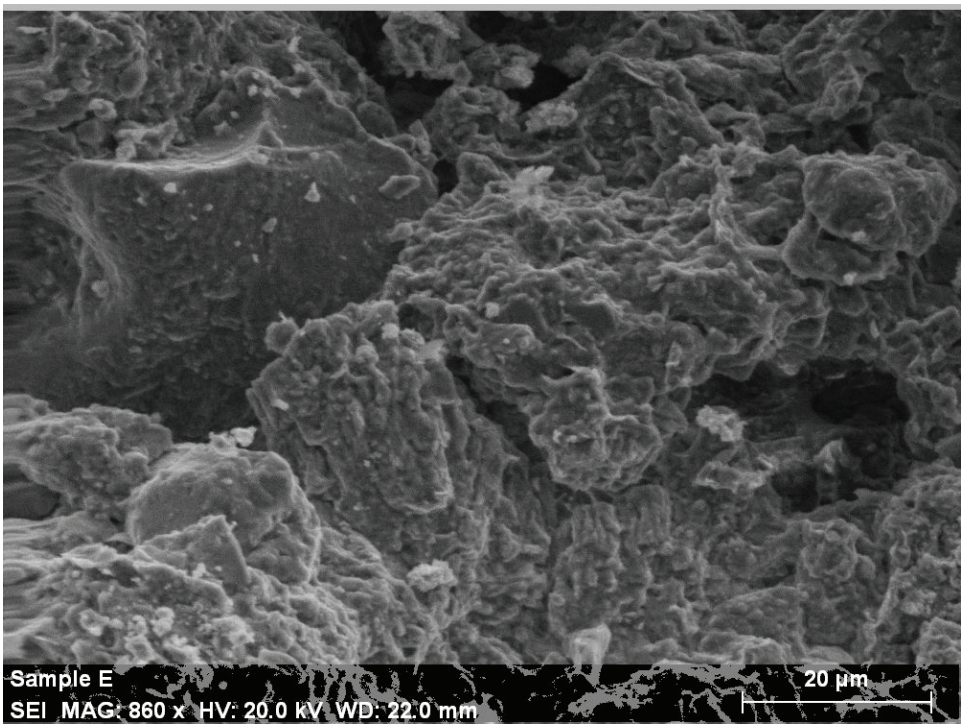


Figure 6.7 Treated sample of delaminated limestone showing TEOS treatment and homogenous film

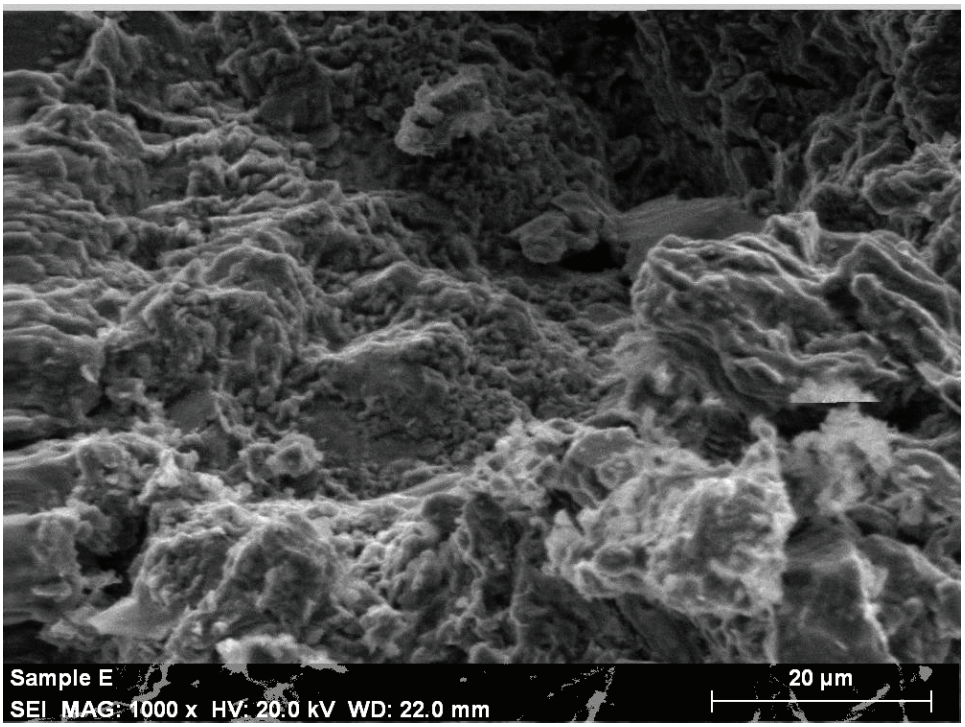


Figure 6.8 Treated sample of delaminated limestone showing homogenous film texture as previously determined by Karas 2011.

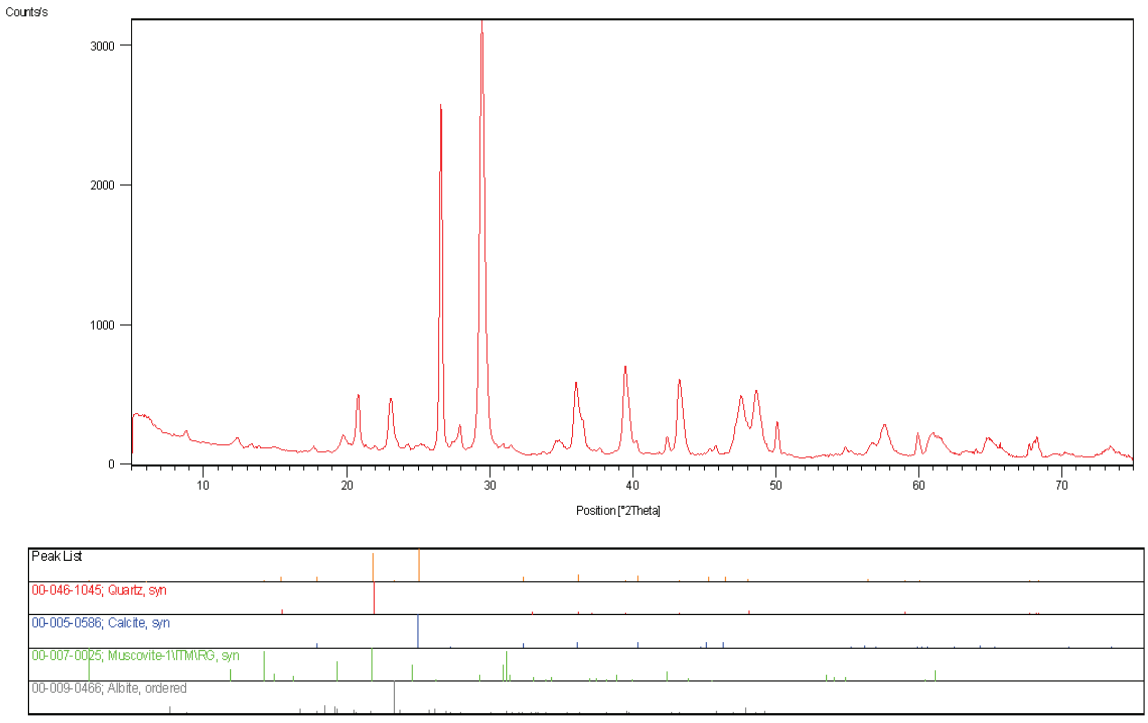
were also visible. This test should be performed with a greater number of samples in order to visually identify a distinct image of expanded clay particles that are not covered by the previous treatment.

6.8 X-RAY DIFFRACTION

6.8.1 Discussion

Preliminary XRD analysis indicates that the powder sample contained predominately calcite with a quartz percentage up to 45%. This is in complete agreement with previous analysis of the San Antonio column stone.[1] The relative intensity of the two main peaks for calcite and quartz indicates their percentage within the stone. Minor phases were difficult to identify in this analysis, as the strongest peaks are usually only detectable. Muscovite and albite are believed to be reasonable matches to the displayed intensity peaks.

[1] Brackin, A. E., 1994, "A Comparative Study of the Effects of Applying Acrylics and Silanes in Sequence and In Mixture with a Case Study of the Column in the Convento of Mission San José Y San Miguel De Agauyo", Graduate Thesis, Univ. Pennsylvania, 10.



Graph 6.8 Graph and peak list created during XRD analysis.

Therefore in order to fully identify the presence of clays within the stone it is recommended that further multi-parameter analysis be performed. Milton's *X-ray Diffraction and the Identification and Analysis of Clay Minerals* (1997) illustrates several methods to isolate the calcite and quartz peaks to obtain an accurate reading of minor phases in low concentrations.

CHAPTER 7: CONCLUSIONS

7.1 EXPERIMENTAL CONCLUSIONS

The results of this study indicated that a consolidation treatment consisting of an anti-swelling pretreatment and an elastified ethyl silicate did not significantly impact the absorption, drying, and water vapor transmission rates of the stone when compared to silicic acid ester OH100. OH100 successfully consolidated the sample but was found to change the aforementioned properties of the stone including a significant color change. Sample C, treated with the Funcosil Antihygro pretreatment and a KSE 300 E consolidant, performed favorably throughout the testing and remains a viable option for treatment. The difference in wetting and drying behavior in samples B and C illustrates the effect the anti-swelling agent has on these process by limiting hygroscopic expansion which lowers absorption rates and increases drying rates.

However the relative durability of such treatment was not able to be determined or compared among the different treatments. The effect of the anti-swelling agent may be further diminished by repeated exposure to climatic conditions and repeated cycles of wetting and drying.

Resistance profiles created for each specific consolidated treatment indicated that the Remmers KSE 300 E and OH100 consolidation treatments greatly increased the strength of the stone and penetrated into the substrate approximately 30mm. The behavior of sample C on the large bulk specimen may indicate either variability within the stone or improper application of the consolidants. Fully consolidated samples analyzed by this method indicated an increased strength on all samples up to 5cm. However, the strength imparted from the consolidation was beyond the capabilities of the DRMS.

7.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Despite several attempts to replicate the damage seen on the column, clay expansion has not been definitively identified as the main deterioration mechanism for the San Antonio Column. Visual imaging through the use of a scanning electron microscopy (SEM) was not able to locate expanded clay grains within samples taken directly from delaminated sections of the column. Preliminary compositional analysis through the use of X-ray diffraction analysis (XRD) indicated the possible presence of swelling clays within the stone but was not able to identify the exact type. It is imperative the mechanism be clearly illustrated before a final conservation treatment program can be initiated

7.3 CONTINUED TESTING

Future work on this subject should propose to continue analysis of the consolidated samples by performing an extended wet/dry cycling test that will attempt to mimic the deterioration seen on the column and assess the durability of the consolidation treatments. Through this method, by visual comparison and analytical tests such as scanning electron microscopy, the expansion of the clays can be illustrated.

7.3.1 Scanning Electron Microscopy

SEM analysis will aid in visualization of the deterioration of the stone and attempt to illustrate the clay particles at different levels of expansion and swelling. Further scanning electron microscopy work should focus on analyzing the consolidant application to the stone and the treatments performance when exposed to simulated conditions.

7.3.2 XRD analysis

Refined multi-parameter XRD analysis will aide in identifying the primary swelling clay that is present within the test samples and the San Antonio Column. Preliminary tests conducted during this study were to asses the bulk characterization of the stone and the data obtained indicated high concentrations of silica and calcite. Specialized methods sample prep will allow the silica and calcite to be filtered from the sample, allowing for a more refined analysis including identification of compounds with minute concentrations.

7.3.3 Drill Resistance with DRMS system

As evidenced by the variability during testing, more refined drilling parameters need to be established. Once this has been achieved, drill resistance measurements of samples subjected to such weathering cycles will highlight the loss of strength and potential success of the anti-swelling inhibitor pretreatment.

7.3 RETREATMENT STUDIES

The retreatment of previously consolidated stone is a burgeoning area of research in the field of architectural conservation and little data remains concerning the effect of several consolidation programs on the same stone. This type of research is of prime importance when considering treatment options for the San Antonio Column. However, this type of condition is extremely difficult to simulate within a laboratory environment and the lack of case studies make this additionally challenging. If successfully consolidated again, The San Antonio Column is a prime example for this type of studied and should be monitored after treatment.

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APPENDIX A:

MANUFACTURERS & SUPPLIERS

APPENDIX A: MANUFACTURERS & SUPPLIERS

ELASTIFIED ETHYL SILICATE

Company: Remmers (U.K.) Limited

Website: www.remmers.co.uk

Phone: 01444-244144

Email: sales@remmers.co.uk

Address:14, Victoria Way--Burgess Hill, West Sussex RH15 9NF

Products:

- Funcosil® Antihygro®
- Funcosil® KSE 300 E

CONSERVARE® OH100

Company: Prosoco

Website: http://www.prosoco.com/

Phone: 1-800-255-4255

Email: customercare@prosoco.com

Address: 3741 Greenway Circle, Lawrence, KS 66046

SCANNING ELECTRON MICROSCOPY

Institution: Winterthur Museum Scientific Research and Analysis Laboratory

Website: http://www.winterthur.org/?p=454

Phone: (800) 448-3883

Address: 5105 Kennett PikeWilmington, DE 19735

Services:

- Scanning electron microscopy

APPENDIX A: MANUFACTURERS & SUPPLIERS

PETROGRAPHIC THIN SECTIONS

Company: National Petrographic Service, Inc.

Website: http://www.nationalpetrographic.com

Phone:(713) 661-1884

Fax: (713) 661-0625

Address: 599 Bellaire Blvd Suite 108 Houston, TX 77081

GLASS CONTAINERS

Company: Wholesale Glass Vases International

Website: http://www.wholesaleglassvasesint.com

Phone: 626-452-8268

Email: sales@WholesaleGlassVasesInt.com

Address: 4063 Temple City Blvd, Building #C

El Monte, CA 91731,

Products: 3” Glass Votives

ADHESIVE TAPE AND SILICONE

Company: 3M

Website: www.3m.com

Phone: (215) 728-5300

Email: http://solutions.3m.com/wps/portal/3M/en_US/WW2/Country/Corp/Contact/

Address: 5698 Rising Sun Avenue Philadelphia, PA 19120

Products: Scotch Super 33+ Vinyl Electric Tape, Super Silicone Sealant

APPENDIX A: MANUFACTURERS & SUPPLIERS

DATA LOGGER

Company: Onset Computer Corporation

Website: http://www.onsetcomp.com/

Phone: (800) 564-4377

Email: customer_service@onsetcomp.com

Address: PO Box 3450 Pocasset, MA 02559-3450

Products:

- HOBO® Data Logger and Software

RELATIVE HUMIDITY SALTS

Company: Fisher Scientific

Website: http://www.fishersci.com

Phone: (800) 766-7000

Email: http://www.fishersci.com/ecomm/servlet/cmstatic?storeId=10652&hreaf=Footer/siteform.jsp&independent=YES

Address: 300 Industry Drive Pittsburgh, PA 15275

Products:

-Calcium Sulfate Dessicant

- Calcium Chloride Dessicant

APPENDIX B:

CAPILLARY ABSORPTION TESTING DATA

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of Untreated Sample A1.1								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass A1.1 (g)	Ut A1.1 (g)	M1 A1.1 (g/cm^2)
4/5/12	9:00 AM	0.00	0	0	0.00	318.14	0.00	0.00
4/5/12	9:05 AM	0.08	5	300	17.32	318.35	0.21	0.01
4/5/12	9:10 AM	0.17	10	600	24.49	318.39	0.25	0.01
4/5/12	9:15 AM	0.25	15	900	30.00	318.41	0.27	0.01
4/5/12	9:20 AM	0.33	20	1200	34.64	318.45	0.31	0.01
4/5/12	9:25 AM	0.42	25	1500	38.73	318.46	0.32	0.01
4/5/12	9:30 AM	0.50	30	1800	42.43	318.48	0.34	0.01
4/5/12	9:35 AM	0.58	35	2100	45.83	318.49	0.35	0.01
4/5/12	9:40 AM	0.67	40	2400	48.99	318.52	0.38	0.01
4/5/12	9:45 AM	0.75	45	2700	51.96	318.55	0.41	0.02
4/5/12	10:00 AM	1.00	60	3600	60.00	318.58	0.44	0.02
4/5/12	10:30 AM	1.50	90	5400	73.48	318.64	0.50	0.02
4/5/12	11:00 AM	2.00	120	7200	84.85	318.70	0.56	0.02
4/5/12	11:30 AM	2.50	150	9000	94.87	318.77	0.63	0.02
4/5/12	12:00 PM	3.00	180	10800	103.92	318.76	0.62	0.02
4/5/12	1:25 PM	4.42	265	15900	126.10	318.91	0.77	0.03
4/5/12	2:00 PM	5.00	300	18000	134.16	318.95	0.81	0.03
4/5/12	3:00 PM	6.00	360	21600	146.97	319.01	0.87	0.03
4/5/12	4:00 PM	7.00	420	25200	158.75	319.09	0.95	0.04
4/5/12	5:00 PM	8.00	480	28800	169.71	319.12	0.98	0.04
4/5/12	6:00 PM	9.00	540	32400	180.00	319.13	0.99	0.04
4/5/12	8:00 PM	11.00	660	39600	199.00	319.23	1.09	0.04
4/5/12	10:41 PM	13.68	821	49260	221.95	319.27	1.13	0.04
4/6/12	12:30 AM	15.50	930	55800	236.22	319.32	1.18	0.05
4/6/12	9:30 AM	24.50	1470	88200	296.98	319.53	1.39	0.05
4/6/12	12:07 PM	27.12	1627	97620	312.44	319.58	1.44	0.06
4/6/12	2:00 PM	29.00	1740	104400	323.11	319.63	1.49	0.06
4/6/12	8:38 PM	35.43	2126	127560	357.16	319.70	1.56	0.06
4/7/12	1:00 AM	40.00	2400	144000	379.47	319.80	1.66	0.06
4/7/12	5:46 PM	56.77	3406	204360	452.06	319.99	1.85	0.07
4/8/12	11:23 AM	74.38	4463	267780	517.47	320.14	2.00	0.08
4/9/12	3:07 PM	102.12	6127	367620	606.32	320.40	2.26	0.09
4/9/12	5:22 PM	104.37	6262	375720	612.96	320.40	2.26	0.09
4/9/12	10:22 PM	109.37	6562	393720	627.47	320.41	2.27	0.09
4/10/12	8:40 AM	119.67	7180	430800	656.35	320.52	2.38	0.09
4/10/12	6:23 PM	129.72	7783	466980	683.36	320.55	2.41	0.09
4/11/12	10:26 AM	145.43	8726	523560	723.57	320.57	2.43	0.09
4/11/12	5:05 PM	152.10	9126	547560	739.97	320.67	2.53	0.10
4/12/12	9:15 AM	168.25	10095	605700	778.27	320.77	2.63	0.10
4/12/12	2:54 PM	173.90	10434	626040	791.23	320.83	2.69	0.10
4/13/12	10:18 AM	193.30	11598	695880	834.19	320.87	2.73	0.11
4/13/12	4:47 PM	199.78	11987	719220	848.07	320.87	2.73	0.11
4/13/12	11:31 PM	206.52	12391	743460	862.24	320.90	2.76	0.11
4/14/12	9:31 AM	216.50	12990	779400	882.84	320.91	2.77	0.11
4/14/12	7:00 PM	226.00	13560	813600	902.00	320.95	2.81	0.11
4/15/12	1:11 PM	244.68	14681	880860	938.54	321.03	2.89	0.11
4/15/12	7:52 PM	250.87	15052	903120	950.33	321.03	2.89	0.11
4/16/12	8:37 AM	275.62	16537	992220	996.10	321.12	2.98	0.12
4/17/12	12:12 PM	292.20	17532	1051920	1025.63	321.20	3.06	0.12
4/17/12	10:07 AM	301.12	18067	1084020	1041.16	321.21	3.07	0.12
4/18/12	11:20 AM	314.33	18860	1131600	1063.77	321.20	3.06	0.12
4/19/12	10:51 AM	331.85	19911	1194660	1093.01	321.25	3.11	0.12
4/21/12	1:58 PM	388.97	23338	1400280	1183.33	321.39	3.25	0.13
4/22/12	4:00 PM	415.00	24900	1494000	1222.29	321.42	3.28	0.13
4/23/12	8:32 AM	431.53	25892	1553520	1246.40	321.47	3.33	0.13
4/24/12	8:22 AM	455.37	27322	1639320	1280.36	321.55	3.41	0.13
4/25/12	10:45 AM	481.75	28905	1734300	1316.93	321.55	3.41	0.13
4/26/12	8:53 AM	503.88	30233	1813980	1346.84	321.59	3.45	0.13
4/27/12	10:04 AM	529.05	31743	1904580	1380.07	321.60	3.46	0.13
4/28/12	2:18 PM	545.28	32717	1963020	1401.08	321.61	3.47	0.13
4/28/12	11:04 PM	566.07	33964	2037840	1427.53	321.63	3.49	0.14
4/29/12	12:34 PM	579.40	34764	2085840	1444.24	321.62	3.48	0.13

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of Untreated Sample A1.2								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass A1.2 (g)	Ut A1.2 (g)	M1 A1.2 (g/cm^2)
4/5/12	9:00 AM	0.00	0	0	0.00	326.78	0	0.00
4/5/12	9:05 AM	0.08	5	300	17.32	327.03	0.25	0.01
4/5/12	9:10 AM	0.17	10	600	24.49	327.08	0.3	0.01
4/5/12	9:15 AM	0.25	15	900	30.00	327.11	0.33	0.01
4/5/12	9:20 AM	0.33	20	1200	34.64	327.15	0.37	0.01
4/5/12	9:25 AM	0.42	25	1500	38.73	327.17	0.39	0.02
4/5/12	9:30 AM	0.50	30	1800	42.43	327.19	0.41	0.02
4/5/12	9:35 AM	0.58	35	2100	45.83	327.21	0.43	0.02
4/5/12	9:40 AM	0.67	40	2400	48.99	327.22	0.44	0.02
4/5/12	9:45 AM	0.75	45	2700	51.96	327.26	0.48	0.02
4/5/12	10:00 AM	1.00	60	3600	60.00	327.29	0.51	0.02
4/5/12	10:30 AM	1.50	90	5400	73.48	327.36	0.58	0.02
4/5/12	11:00 AM	2.00	120	7200	84.85	327.46	0.68	0.03
4/5/12	11:30 AM	2.50	150	9000	94.87	327.55	0.77	0.03
4/5/12	12:00 PM	3.00	180	10800	103.92	327.55	0.77	0.03
4/5/12	1:25 PM	4.42	265	15900	126.10	327.7	0.92	0.04
4/5/12	2:00 PM	5.00	300	18000	134.16	327.77	0.99	0.04
4/5/12	3:00 PM	6.00	360	21600	146.97	327.86	1.08	0.04
4/5/12	4:00 PM	7.00	420	25200	158.75	327.94	1.16	0.04
4/5/12	5:00 PM	8.00	480	28800	169.71	327.99	1.21	0.05
4/5/12	6:00 PM	9.00	540	32400	180.00	328.03	1.25	0.05
4/5/12	8:00 PM	11.00	660	39600	199.00	328.12	1.34	0.05
4/5/12	10:41 PM	13.68	821	49260	221.95	328.24	1.46	0.06
4/6/12	12:30 AM	15.50	930	55800	236.22	328.35	1.57	0.06
4/6/12	9:30 AM	24.50	1470	88200	296.98	328.6	1.82	0.07
4/6/12	12:07 PM	27.12	1627	97620	312.44	328.67	1.89	0.07
4/6/12	2:00 PM	29.00	1740	104400	323.11	328.73	1.95	0.08
4/6/12	8:38 PM	35.43	2126	127560	357.16	328.84	2.06	0.08
4/7/12	1:00 AM	40.00	2400	144000	379.47	328.93	2.15	0.08
4/7/12	5:46 PM	56.77	3406	204360	452.06	329.19	2.41	0.09
4/8/12	11:23 AM	74.38	4463	267780	517.47	329.4	2.62	0.10
4/9/12	3:07 PM	102.12	6127	367620	606.32	329.69	2.91	0.11
4/9/12	5:22 PM	104.37	6262	375720	612.96	329.73	2.95	0.11
4/9/12	10:22 PM	109.37	6562	393720	627.47	329.73	2.95	0.11
4/10/12	8:40 AM	119.67	7180	430800	656.35	329.83	3.05	0.12
4/10/12	6:23 PM	129.72	7783	466980	683.36	329.91	3.13	0.12
4/11/12	10:26 AM	145.43	8726	523560	723.57	329.91	3.13	0.12
4/11/12	5:05 PM	152.10	9126	547560	739.97	329.95	3.17	0.12
4/12/12	9:15 AM	168.25	10095	605700	778.27	330.13	3.35	0.13
4/12/12	2:54 PM	173.90	10434	626040	791.23	330.18	3.4	0.13
4/13/12	10:18 AM	193.30	11598	695880	834.19	330.28	3.5	0.14
4/13/12	4:47 PM	199.78	11987	719220	848.07	330.29	3.51	0.14
4/13/12	11:31 PM	206.52	12391	743460	862.24	330.29	3.51	0.14
4/14/12	9:31 AM	216.50	12990	779400	882.84	330.32	3.54	0.14
4/14/12	7:00 PM	226.00	13560	813600	902.00	330.36	3.58	0.14
4/15/12	1:11 PM	244.68	14681	880860	938.54	330.41	3.63	0.14
4/15/12	7:52 PM	250.87	15052	903120	950.33	330.41	3.63	0.14
4/16/12	8:37 AM	275.62	16537	992220	996.10	330.49	3.71	0.14
4/17/12	12:12 PM	292.20	17532	1051920	1025.63	330.54	3.76	0.15
4/17/12	10:07 AM	301.12	18067	1084020	1041.16	330.55	3.77	0.15
4/18/12	11:20 AM	314.33	18860	1131600	1063.77	330.55	3.77	0.15
4/19/12	10:51 AM	331.85	19911	1194660	1093.01	330.6	3.82	0.15
4/21/12	1:58 PM	388.97	23338	1400280	1183.33	330.72	3.94	0.15
4/22/12	4:00 PM	415.00	24900	1494000	1222.29	330.76	3.98	0.15
4/23/12	8:32 AM	431.53	25892	1553520	1246.40	330.79	4.01	0.16
4/24/12	8:22 AM	455.37	27322	1639320	1280.36	330.82	4.04	0.16
4/25/12	10:45 AM	481.75	28905	1734300	1316.93	330.83	4.05	0.16
4/26/12	8:53 AM	503.88	30233	1813980	1346.84	330.88	4.1	0.16
4/27/12	10:04 AM	529.05	31743	1904580	1380.07	330.87	4.09	0.16
4/28/12	2:18 PM	545.28	32717	1963020	1401.08	330.88	4.1	0.16
4/28/12	11:04 PM	566.07	33964	2037840	1427.53	330.87	4.09	0.16
4/29/12	12:34 PM	579.40	34764	2085840	1444.24	330.87	4.09	0.16

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of Untreated Sample A1.3								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass A1.3 (g)	Ut A1.3 (g)	M1 A1.3 (g/cm^2)
4/5/12	9:00 AM	0.00	0	0	0.00	318.8	0	0.00
4/5/12	9:05 AM	0.08	5	300	17.32	319.01	0.21	0.01
4/5/12	9:10 AM	0.17	10	600	24.49	319.06	0.26	0.01
4/5/12	9:15 AM	0.25	15	900	30.00	319.09	0.29	0.01
4/5/12	9:20 AM	0.33	20	1200	34.64	319.13	0.33	0.01
4/5/12	9:25 AM	0.42	25	1500	38.73	319.16	0.36	0.01
4/5/12	9:30 AM	0.50	30	1800	42.43	319.17	0.37	0.01
4/5/12	9:35 AM	0.58	35	2100	45.83	319.21	0.41	0.02
4/5/12	9:40 AM	0.67	40	2400	48.99	319.21	0.41	0.02
4/5/12	9:45 AM	0.75	45	2700	51.96	319.22	0.42	0.02
4/5/12	10:00 AM	1.00	60	3600	60.00	319.26	0.46	0.02
4/5/12	10:30 AM	1.50	90	5400	73.48	319.35	0.55	0.02
4/5/12	11:00 AM	2.00	120	7200	84.85	319.51	0.71	0.03
4/5/12	11:30 AM	2.50	150	9000	94.87	319.55	0.75	0.03
4/5/12	12:00 PM	3.00	180	10800	103.92	319.57	0.77	0.03
4/5/12	1:25 PM	4.42	265	15900	126.10	319.71	0.91	0.04
4/5/12	2:00 PM	5.00	300	18000	134.16	319.79	0.99	0.04
4/5/12	3:00 PM	6.00	360	21600	146.97	319.87	1.07	0.04
4/5/12	4:00 PM	7.00	420	25200	158.75	319.93	1.13	0.04
4/5/12	5:00 PM	8.00	480	28800	169.71	320	1.2	0.05
4/5/12	6:00 PM	9.00	540	32400	180.00	320.02	1.22	0.05
4/5/12	8:00 PM	11.00	660	39600	199.00	320.15	1.35	0.05
4/5/12	10:41 PM	13.68	821	49260	221.95	320.19	1.39	0.05
4/6/12	12:30 AM	15.50	930	55800	236.22	320.23	1.43	0.06
4/6/12	9:30 AM	24.50	1470	88200	296.98	320.54	1.74	0.07
4/6/12	12:07 PM	27.12	1627	97620	312.44	320.59	1.79	0.07
4/6/12	2:00 PM	29.00	1740	104400	323.11	320.67	1.87	0.07
4/6/12	8:38 PM	35.43	2126	127560	357.16	320.78	1.98	0.08
4/7/12	1:00 AM	40.00	2400	144000	379.47	320.85	2.05	0.08
4/7/12	5:46 PM	56.77	3406	204360	452.06	321.13	2.33	0.09
4/8/12	11:23 AM	74.38	4463	267780	517.47	321.37	2.57	0.10
4/9/12	3:07 PM	102.12	6127	367620	606.32	321.71	2.91	0.11
4/9/12	5:22 PM	104.37	6262	375720	612.96	321.74	2.94	0.11
4/9/12	10:22 PM	109.37	6562	393720	627.47	321.76	2.96	0.11
4/10/12	8:40 AM	119.67	7180	430800	656.35	321.9	3.1	0.12
4/10/12	6:23 PM	129.72	7783	466980	683.36	322.01	3.21	0.12
4/11/12	10:26 AM	145.43	8726	523560	723.57	322.05	3.25	0.13
4/11/12	5:05 PM	152.10	9126	547560	739.97	322.08	3.28	0.13
4/12/12	9:15 AM	168.25	10095	605700	778.27	322.27	3.47	0.13
4/12/12	2:54 PM	173.90	10434	626040	791.23	322.33	3.53	0.14
4/13/12	10:18 AM	193.30	11598	695880	834.19	322.45	3.65	0.14
4/13/12	4:47 PM	199.78	11987	719220	848.07	322.49	3.69	0.14
4/13/12	11:31 PM	206.52	12391	743460	862.24	322.49	3.69	0.14
4/14/12	9:31 AM	216.50	12990	779400	882.84	322.53	3.73	0.14
4/14/12	7:00 PM	226.00	13560	813600	902.00	322.59	3.79	0.15
4/15/12	1:11 PM	244.68	14681	880860	938.54	322.61	3.81	0.15
4/15/12	7:52 PM	250.87	15052	903120	950.33	322.6	3.8	0.15
4/16/12	8:37 AM	275.62	16537	992220	996.10	322.74	3.94	0.15
4/17/12	12:12 PM	292.20	17532	1051920	1025.63	322.8	4	0.16
4/17/12	10:07 AM	301.12	18067	1084020	1041.16	322.87	4.07	0.16
4/18/12	11:20 AM	314.33	18860	1131600	1063.77	322.87	4.07	0.16
4/19/12	10:51 AM	331.85	19911	1194660	1093.01	322.9	4.1	0.16
4/21/12	1:58 PM	388.97	23338	1400280	1183.33	323.06	4.26	0.17
4/22/12	4:00 PM	415.00	24900	1494000	1222.29	323.11	4.31	0.17
4/23/12	8:32 AM	431.53	25892	1553520	1246.40	323.1	4.3	0.17
4/24/12	8:22 AM	455.37	27322	1639320	1280.36	323.18	4.38	0.17
4/25/12	10:45 AM	481.75	28905	1734300	1316.93	323.19	4.39	0.17
4/26/12	8:53 AM	503.88	30233	1813980	1346.84	323.2	4.4	0.17
4/27/12	10:04 AM	529.05	31743	1904580	1380.07	323.21	4.41	0.17
4/28/12	2:18 PM	545.28	32717	1963020	1401.08	323.21	4.41	0.17
4/28/12	11:04 PM	566.07	33964	2037840	1427.53	323.21	4.41	0.17
4/29/12	12:34 PM	579.40	34764	2085840	1444.24	323.2	4.4	0.17

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of KSE 300E Sample B1.1								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:00 AM	0.00	0	0	0.00	317.16	0.00	0.00
4/5/12	9:05 AM	0.08	5	300	17.32	317.22	0.06	0.00
4/5/12	9:10 AM	0.17	10	600	24.49	317.25	0.09	0.00
4/5/12	9:15 AM	0.25	15	900	30.00	317.26	0.10	0.00
4/5/12	9:20 AM	0.33	20	1200	34.64	317.27	0.11	0.00
4/5/12	9:25 AM	0.42	25	1500	38.73	317.27	0.11	0.00
4/5/12	9:30 AM	0.50	30	1800	42.43	317.28	0.12	0.00
4/5/12	9:35 AM	0.58	35	2100	45.83	317.28	0.12	0.00
4/5/12	9:40 AM	0.67	40	2400	48.99	317.28	0.12	0.00
4/5/12	9:45 AM	0.75	45	2700	51.96	317.31	0.15	0.01
4/5/12	10:00 AM	1.00	60	3600	60.00	317.31	0.15	0.01
4/5/12	10:30 AM	1.50	90	5400	73.48	317.31	0.15	0.01
4/5/12	11:00 AM	2.00	120	7200	84.85	317.36	0.20	0.01
4/5/12	11:30 AM	2.50	150	9000	94.87	317.35	0.19	0.01
4/5/12	12:00 PM	3.00	180	10800	103.92	317.33	0.17	0.01
4/5/12	1:25 PM	4.42	265	15900	126.10	317.40	0.24	0.01
4/5/12	2:00 PM	5.00	300	18000	134.16	317.40	0.24	0.01
4/5/12	3:00 PM	6.00	360	21600	146.97	317.43	0.27	0.01
4/5/12	4:00 PM	7.00	420	25200	158.75	317.45	0.29	0.01
4/5/12	5:00 PM	8.00	480	28800	169.71	317.48	0.32	0.01
4/5/12	6:00 PM	9.00	540	32400	180.00	317.48	0.32	0.01
4/5/12	8:00 PM	11.00	660	39600	199.00	317.49	0.33	0.01
4/5/12	10:41 PM	13.68	821	49260	221.95	317.53	0.37	0.01
4/6/12	12:30 AM	15.50	930	55800	236.22	317.58	0.42	0.02
4/6/12	9:30 AM	24.50	1470	88200	296.98	317.77	0.61	0.02
4/6/12	12:07 PM	27.12	1627	97620	312.44	317.79	0.63	0.02
4/6/12	2:00 PM	29.00	1740	104400	323.11	317.84	0.68	0.03
4/6/12	8:38 PM	35.43	2126	127560	357.16	317.88	0.72	0.03
4/7/12	1:00 AM	40.00	2400	144000	379.47	317.97	0.81	0.03
4/7/12	5:46 AM	56.77	3406	204360	452.06	318.20	1.04	0.04
4/8/12	11:23 AM	74.38	4463	267780	517.47	318.40	1.24	0.05
4/9/12	3:07 PM	102.12	6127	367620	606.32	318.78	1.62	0.06
4/9/12	5:22 PM	104.37	6262	375720	612.96	318.80	1.64	0.06
4/9/12	10:22 PM	109.37	6562	393720	627.47	318.83	1.67	0.06
4/10/12	8:40 AM	119.67	7180	430800	656.35	318.99	1.83	0.07
4/10/12	6:23 PM	129.72	7783	466980	683.36	319.12	1.96	0.08
4/11/12	10:26 AM	145.43	8726	523560	723.57	319.28	2.12	0.08
4/11/12	5:05 PM	152.10	9126	547560	739.97	319.28	2.12	0.08
4/12/12	9:15 AM	168.25	10095	605700	778.27	319.54	2.38	0.09
4/12/12	2:54 PM	173.90	10434	626040	791.23	319.64	2.48	0.10
4/13/12	10:18 AM	193.30	11598	695880	834.19	319.83	2.67	0.10
4/13/12	4:47 PM	199.78	11987	719220	848.07	319.88	2.72	0.11
4/13/12	11:31 PM	206.52	12391	743460	862.24	319.94	2.78	0.11
4/14/12	9:31 AM	216.50	12990	779400	882.84	320.00	2.84	0.11
4/14/12	7:03 PM	226.00	13560	813600	902.00	320.11	2.95	0.11
4/15/12	1:11 PM	244.68	14681	880860	938.54	320.24	3.08	0.12
4/15/12	7:53 PM	250.87	15052	903120	950.33	320.28	3.12	0.12
4/16/12	8:39 AM	275.62	16537	992220	996.10	320.56	3.40	0.13
4/17/12	12:13 PM	292.20	17532	1051920	1025.63	320.66	3.50	0.14
4/17/12	10:08 AM	301.12	18067	1084020	1041.16	320.76	3.60	0.14
4/18/12	11:21 AM	314.33	18860	1131600	1063.77	320.75	3.59	0.14
4/19/12	10:52 AM	331.85	19911	1194660	1093.01	320.99	3.83	0.15
4/20/12	6:02 PM	358.02	21481	1288860	1135.28	321.26	4.10	0.16
4/21/12	1:59 PM	388.97	23338	1400280	1183.33	321.32	4.16	0.16
4/22/12	4:01 PM	415.00	24900	1494000	1222.29	321.42	4.26	0.17
4/23/12	8:33 AM	431.53	25892	1553520	1246.40	321.41	4.25	0.16
4/24/12	8:23 AM	455.37	27322	1639320	1280.36	321.49	4.33	0.17
4/25/12	10:46 AM	481.75	28905	1734300	1316.93	321.50	4.34	0.17
4/26/12	8:54 AM	503.88	30233	1813980	1346.84	321.54	4.38	0.17
4/27/12	10:06 AM	529.05	31743	1904580	1380.07	321.62	4.46	0.17
4/28/12	2:19 AM	545.28	32717	1963020	1401.08	321.62	4.46	0.17
4/28/12	11:05 PM	566.07	33964	2037840	1427.53	321.62	4.46	0.17
4/29/12	12:36 PM	579.40	34764	2085840	1444.24	321.64	4.46	0.17
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	321.65	4.46	0.17

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of KSE 300E Sample B1.2								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:02 AM	0.00	0	0	0.00	320.83	0.00	0.00
4/5/12	9:07 AM	0.08	5	300	17.32	320.88	0.05	0.00
4/5/12	9:12 AM	0.17	10	600	24.49	320.89	0.06	0.00
4/5/12	9:17 AM	0.25	15	900	30.00	320.90	0.07	0.00
4/5/12	9:22 AM	0.33	20	1200	34.64	320.91	0.08	0.00
4/5/12	9:27 AM	0.42	25	1500	38.73	320.92	0.09	0.00
4/5/12	9:32 AM	0.50	30	1800	42.43	320.90	0.07	0.00
4/5/12	9:37 AM	0.58	35	2100	45.83	320.92	0.09	0.00
4/5/12	9:42 AM	0.67	40	2400	48.99	320.92	0.09	0.00
4/5/12	9:47 AM	0.75	45	2700	51.96	320.93	0.10	0.00
4/5/12	10:02 AM	1.00	60	3600	60.00	320.94	0.11	0.00
4/5/12	10:32 AM	1.50	90	5400	73.48	320.94	0.11	0.00
4/5/12	11:02 AM	2.00	120	7200	84.85	320.98	0.15	0.01
4/5/12	11:32 AM	2.50	150	9000	94.87	320.99	0.16	0.01
4/5/12	12:02 PM	3.00	180	10800	103.92	321.00	0.17	0.01
4/5/12	1:27 PM	4.38	263	15780	125.62	321.02	0.19	0.01
4/5/12	2:02 PM	5.00	300	18000	134.16	321.02	0.19	0.01
4/5/12	3:02 PM	6.00	360	21600	146.97	321.05	0.22	0.01
4/5/12	4:02 PM	7.00	420	25200	158.75	321.05	0.22	0.01
4/5/12	5:02 PM	8.00	480	28800	169.71	321.07	0.24	0.01
4/5/12	6:02 PM	9.00	540	32400	180.00	321.07	0.24	0.01
4/5/12	8:02 PM	11.00	660	39600	199.00	321.08	0.25	0.01
4/5/12	10:43 PM	13.68	821	49260	221.95	321.10	0.27	0.01
4/6/12	12:32 AM	15.50	930	55800	236.22	321.12	0.29	0.01
4/6/12	9:32 AM	24.50	1470	88200	296.98	321.25	0.42	0.02
4/6/12	12:09 PM	27.12	1627	97620	312.44	321.25	0.42	0.02
4/6/12	2:02 PM	29.00	1740	104400	323.11	321.26	0.43	0.02
4/6/12	8:40 PM	35.43	2126	127560	357.16	321.28	0.45	0.02
4/7/12	1:02 AM	40.00	2400	144000	379.47	321.29	0.46	0.02
4/7/12	5:48 PM	56.77	3406	204360	452.06	321.43	0.60	0.02
4/8/12	11:25 AM	74.38	4463	267780	517.47	321.53	0.70	0.03
4/9/12	3:09 PM	102.12	6127	367620	606.32	321.68	0.85	0.03
4/9/12	5:24 PM	104.37	6262	375720	612.96	321.68	0.85	0.03
4/9/12	10:24 PM	109.37	6562	393720	627.47	321.70	0.87	0.03
4/10/12	8:42 AM	119.67	7180	430800	656.35	321.80	0.97	0.04
4/10/12	6:25 PM	129.72	7783	466980	683.36	321.83	1.00	0.04
4/11/12	10:28 AM	145.43	8726	523560	723.57	321.88	1.05	0.04
4/11/12	5:07 PM	152.10	9126	547560	739.97	321.90	1.07	0.04
4/12/12	9:17 AM	168.25	10095	605700	778.27	322.01	1.18	0.05
4/12/12	2:56 PM	173.90	10434	626040	791.23	322.06	1.23	0.05
4/13/12	10:20 AM	193.30	11598	695880	834.19	322.15	1.32	0.05
4/13/12	4:49 PM	199.78	11987	719220	848.07	322.16	1.33	0.05
4/13/12	11:33 PM	206.52	12391	743460	862.24	322.17	1.34	0.05
4/14/12	9:33 AM	216.50	12990	779400	882.84	322.16	1.33	0.05
4/14/12	7:03 PM	226.00	13560	813600	902.00	322.27	1.44	0.06
4/15/12	1:11 PM	244.68	14681	880860	938.54	322.29	1.46	0.06
4/15/12	7:53 PM	250.87	15052	903120	950.33	322.29	1.46	0.06
4/16/12	8:39 AM	275.62	16537	992220	996.10	322.42	1.59	0.06
4/17/12	12:13 PM	292.20	17532	1051920	1025.63	322.44	1.61	0.06
4/17/12	10:08 AM	301.12	18067	1084020	1041.16	322.52	1.69	0.07
4/18/12	11:21 AM	314.33	18860	1131600	1063.77	322.55	1.72	0.07
4/19/12	10:52 AM	331.85	19911	1194660	1093.01	322.61	1.78	0.07
4/20/12	6:02 PM	358.02	21481	1288860	1135.28	322.80	1.97	0.08
4/21/12	1:59 PM	388.97	23338	1400280	1183.33	322.83	2.00	0.08
4/22/12	4:01 PM	415.00	24900	1494000	1222.29	322.89	2.06	0.08
4/23/12	8:33 AM	431.53	25892	1553520	1246.40	322.95	2.12	0.08
4/24/12	8:23 AM	455.37	27322	1639320	1280.36	323.01	2.18	0.08
4/25/12	10:46 AM	481.75	28905	1734300	1316.93	323.07	2.24	0.09
4/26/12	8:54 AM	503.88	30233	1813980	1346.84	323.09	2.26	0.09
4/27/12	10:06 AM	529.05	31743	1904580	1380.07	323.20	2.37	0.09
4/28/12	2:19 AM	545.28	32717	1963020	1401.08	323.22	2.39	0.09
4/28/12	11:05 PM	566.07	33964	2037840	1427.53	323.33	2.50	0.10
4/29/12	12:36 PM	579.40	34764	2085840	1444.24	323.33	2.50	0.10
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	323.31	2.50	0.10

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of KSE 300E Sample B1.3								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:02 AM	0.00	0	0	0.00	323.48	0.00	0.00
4/5/12	9:07 AM	0.08	5	300	17.32	323.55	0.07	0.00
4/5/12	9:12 AM	0.17	10	600	24.49	323.55	0.07	0.00
4/5/12	9:17 AM	0.25	15	900	30.00	323.55	0.07	0.00
4/5/12	9:22 AM	0.33	20	1200	34.64	323.56	0.08	0.00
4/5/12	9:27 AM	0.42	25	1500	38.73	323.58	0.10	0.00
4/5/12	9:32 AM	0.50	30	1800	42.43	323.58	0.10	0.00
4/5/12	9:37 AM	0.58	35	2100	45.83	323.59	0.11	0.00
4/5/12	9:42 AM	0.67	40	2400	48.99	323.58	0.10	0.00
4/5/12	9:47 AM	0.75	45	2700	51.96	323.59	0.11	0.00
4/5/12	10:02 AM	1.00	60	3600	60.00	323.60	0.12	0.00
4/5/12	10:32 AM	1.50	90	5400	73.48	323.62	0.14	0.01
4/5/12	11:02 AM	2.00	120	7200	84.85	323.64	0.16	0.01
4/5/12	11:32 AM	2.50	150	9000	94.87	323.65	0.17	0.01
4/5/12	12:02 PM	3.00	180	10800	103.92	323.63	0.15	0.01
4/5/12	1:27 PM	4.38	263	15780	125.62	323.72	0.24	0.01
4/5/12	2:02 PM	5.00	300	18000	134.16	323.72	0.24	0.01
4/5/12	3:02 PM	6.00	360	21600	146.97	323.75	0.27	0.01
4/5/12	4:02 PM	7.00	420	25200	158.75	323.76	0.28	0.01
4/5/12	5:02 PM	8.00	480	28800	169.71	323.77	0.29	0.01
4/5/12	6:02 PM	9.00	540	32400	180.00	323.79	0.31	0.01
4/5/12	8:02 PM	11.00	660	39600	199.00	323.86	0.38	0.01
4/5/12	10:43 PM	13.68	821	49260	221.95	323.88	0.40	0.02
4/6/12	12:32 AM	15.50	930	55800	236.22	323.90	0.42	0.02
4/6/12	9:32 AM	24.50	1470	88200	296.98	324.10	0.62	0.02
4/6/12	12:09 PM	27.12	1627	97620	312.44	324.12	0.64	0.02
4/6/12	2:02 PM	29.00	1740	104400	323.11	324.15	0.67	0.03
4/6/12	8:40 PM	35.43	2126	127560	357.16	324.22	0.74	0.03
4/7/12	1:02 AM	40.00	2400	144000	379.47	324.24	0.76	0.03
4/7/12	5:48 PM	56.77	3406	204360	452.06	324.51	1.03	0.04
4/8/12	11:25 AM	74.38	4463	267780	517.47	324.69	1.21	0.05
4/9/12	3:09 PM	102.12	6127	367620	606.32	324.94	1.46	0.06
4/9/12	5:24 PM	104.37	6262	375720	612.96	324.94	1.46	0.06
4/9/12	10:24 PM	109.37	6562	393720	627.47	324.95	1.47	0.06
4/10/12	8:42 AM	119.67	7180	430800	656.35	325.08	1.60	0.06
4/10/12	6:25 PM	129.72	7783	466980	683.36	325.12	1.64	0.06
4/11/12	10:28 AM	145.43	8726	523560	723.57	325.29	1.81	0.07
4/11/12	5:07 PM	152.10	9126	547560	739.97	325.30	1.82	0.07
4/12/12	9:17 AM	168.25	10095	605700	778.27	325.50	2.02	0.08
4/12/12	2:56 PM	173.90	10434	626040	791.23	325.56	2.08	0.08
4/13/12	10:20 AM	193.30	11598	695880	834.19	325.72	2.24	0.09
4/13/12	4:49 PM	199.78	11987	719220	848.07	325.72	2.24	0.09
4/13/12	11:33 PM	206.52	12391	743460	862.24	325.78	2.30	0.09
4/14/12	9:33 AM	216.50	12990	779400	882.84	325.85	2.37	0.09
4/14/12	7:03 PM	226.00	13560	813600	902.00	325.94	2.46	0.10
4/15/12	1:11 PM	244.68	14681	880860	938.54	326.02	2.54	0.10
4/15/12	7:53 PM	250.87	15052	903120	950.33	326.05	2.57	0.10
4/16/12	8:39 AM	275.62	16537	992220	996.10	326.22	2.74	0.11
4/17/12	12:13 PM	292.20	17532	1051920	1025.63	326.31	2.83	0.11
4/17/12	10:08 AM	301.12	18067	1084020	1041.16	326.37	2.89	0.11
4/18/12	11:21 AM	314.33	18860	1131600	1063.77	326.41	2.93	0.11
4/19/12	10:52 AM	331.85	19911	1194660	1093.01	326.56	3.08	0.12
4/20/12	6:02 PM	358.02	21481	1288860	1135.28	326.82	3.34	0.13
4/21/12	1:59 PM	388.97	23338	1400280	1183.33	326.88	3.40	0.13
4/22/12	4:01 PM	415.00	24900	1494000	1222.29	326.95	3.47	0.13
4/23/12	8:33 AM	431.53	25892	1553520	1246.40	327.03	3.55	0.14
4/24/12	8:23 AM	455.37	27322	1639320	1280.36	327.09	3.61	0.14
4/25/12	10:46 AM	481.75	28905	1734300	1316.93	327.15	3.67	0.14
4/26/12	8:54 AM	503.88	30233	1813980	1346.84	327.24	3.76	0.15
4/27/12	10:06 AM	529.05	31743	1904580	1380.07	327.35	3.87	0.15
4/28/12	2:19 AM	545.28	32717	1963020	1401.08	327.37	3.97	0.15
4/28/12	11:05 PM	566.07	33964	2037840	1427.53	327.45	3.97	0.15
4/29/12	12:36 PM	579.40	34764	2085840	1444.24	327.44	3.96	0.15
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	327.45	3.97	0.15

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of ANTIHYGRO + KSE 300E Sample C1.1								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:02 AM	0.00	0	0	0.00	324.97	0.00	0.00
4/5/12	9:07 AM	0.08	5	300	17.32	325.04	0.07	0.00
4/5/12	9:12 AM	0.17	10	600	24.49	325.05	0.08	0.00
4/5/12	9:17 AM	0.25	15	900	30.00	325.06	0.09	0.00
4/5/12	9:22 AM	0.33	20	1200	34.64	325.08	0.11	0.00
4/5/12	9:27 AM	0.42	25	1500	38.73	325.08	0.11	0.00
4/5/12	9:32 AM	0.50	30	1800	42.43	325.10	0.13	0.01
4/5/12	9:37 AM	0.58	35	2100	45.83	325.10	0.13	0.01
4/5/12	9:42 AM	0.67	40	2400	48.99	325.11	0.14	0.01
4/5/12	9:47 AM	0.75	45	2700	51.96	325.11	0.14	0.01
4/5/12	10:02 AM	1.00	60	3600	60.00	325.13	0.16	0.01
4/5/12	10:32 AM	1.50	90	5400	73.48	325.15	0.18	0.01
4/5/12	11:02 AM	2.00	120	7200	84.85	325.19	0.22	0.01
4/5/12	11:32 AM	2.50	150	9000	94.87	325.20	0.23	0.01
4/5/12	12:02 PM	3.00	180	10800	103.92	325.18	0.21	0.01
4/5/12	1:27 PM	4.38	263	15780	125.62	325.24	0.27	0.01
4/5/12	2:02 PM	5.00	300	18000	134.16	325.24	0.27	0.01
4/5/12	3:02 PM	6.00	360	21600	146.97	325.26	0.29	0.01
4/5/12	4:02 PM	7.00	420	25200	158.75	325.27	0.30	0.01
4/5/12	5:02 PM	8.00	480	28800	169.71	325.27	0.30	0.01
4/5/12	6:02 PM	9.00	540	32400	180.00	325.30	0.33	0.01
4/5/12	8:02 PM	11.00	660	39600	199.00	325.33	0.36	0.01
4/5/12	10:43 PM	13.68	821	49260	221.95	325.35	0.38	0.01
4/6/12	12:32 AM	15.50	930	55800	236.22	325.41	0.44	0.02
4/6/12	9:32 AM	24.50	1470	88200	296.98	325.54	0.57	0.02
4/6/12	12:09 PM	27.12	1627	97620	312.44	325.54	0.57	0.02
4/6/12	2:02 PM	29.00	1740	104400	323.11	325.52	0.55	0.02
4/6/12	8:40 PM	35.43	2126	127560	357.16	325.60	0.63	0.02
4/7/12	1:02 AM	40.00	2400	144000	379.47	325.60	0.63	0.02
4/7/12	5:48 AM	56.77	3406	204360	452.06	325.70	0.73	0.03
4/8/12	11:25 AM	74.38	4463	267780	517.47	325.91	0.94	0.04
4/9/12	3:09 PM	102.12	6127	367620	606.32	326.11	1.14	0.04
4/9/12	5:24 PM	104.37	6262	375720	612.96	326.11	1.14	0.04
4/9/12	10:24 PM	109.37	6562	393720	627.47	326.11	1.14	0.04
4/10/12	8:42 AM	119.67	7180	430800	656.35	326.20	1.23	0.05
4/10/12	6:25 PM	129.72	7783	466980	683.36	326.26	1.29	0.05
4/11/12	10:28 AM	145.43	8726	523560	723.57	326.32	1.35	0.05
4/11/12	5:07 PM	152.10	9126	547560	739.97	326.33	1.36	0.05
4/12/12	9:17 AM	168.25	10095	605700	778.27	326.45	1.48	0.06
4/12/12	2:56 PM	173.90	10434	626040	791.23	326.48	1.51	0.06
4/13/12	10:20 AM	193.30	11598	695880	834.19	326.55	1.58	0.06
4/13/12	4:49 PM	199.78	11987	719220	848.07	326.62	1.65	0.06
4/13/12	11:33 PM	206.52	12391	743460	862.24	326.62	1.65	0.06
4/14/12	9:33 AM	216.50	12990	779400	882.84	326.65	1.68	0.07
4/14/12	7:03 PM	226.00	13560	813600	902.00	326.70	1.73	0.07
4/15/12	1:11 PM	244.68	14681	880860	938.54	326.72	1.75	0.07
4/15/12	7:54 PM	250.87	15052	903120	950.33	326.78	1.81	0.07
4/16/12	8:40 AM	275.62	16537	992220	996.10	326.88	1.91	0.07
4/17/12	12:14 PM	292.20	17532	1051920	1025.63	326.92	1.95	0.08
4/17/12	10:09 AM	301.12	18067	1084020	1041.16	326.96	1.99	0.08
4/19/12	10:54 AM	331.85	19911	1194660	1093.01	327.07	2.10	0.08
4/21/12	2:00 PM	388.97	23338	1400280	1183.33	327.27	2.30	0.09
4/22/12	4:02 PM	415.00	24900	1494000	1222.29	327.32	2.35	0.09
4/23/12	8:34 PM	431.53	25892	1553520	1246.40	327.39	2.42	0.09
4/24/12	8:24 AM	455.37	27322	1639320	1280.36	327.46	2.49	0.10
4/25/12	10:47 AM	481.75	28905	1734300	1316.93	327.55	2.58	0.10
4/26/12	8:55 AM	503.88	30233	1813980	1346.84	327.60	2.63	0.10
4/27/12	10:08 AM	529.05	31743	1904580	1380.07	327.75	2.78	0.11
4/28/12	11:06 PM	566.07	33964	2037840	1427.53	327.84	2.87	0.11
4/29/12	12:37 PM	579.40	34764	2085840	1444.24	327.84	2.87	0.11
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	327.84	2.87	0.11

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of ANTIHYGRO + KSE 300E Sample C1.2								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:02 AM	0.00	0	0	0.00	320.62	0.00	0.00
4/5/12	9:07 AM	0.08	5	300	17.32	320.67	0.05	0.00
4/5/12	9:12 AM	0.17	10	600	24.49	320.69	0.07	0.00
4/5/12	9:17 AM	0.25	15	900	30.00	320.69	0.07	0.00
4/5/12	9:22 AM	0.33	20	1200	34.64	320.72	0.10	0.00
4/5/12	9:27 AM	0.42	25	1500	38.73	320.72	0.10	0.00
4/5/12	9:32 AM	0.50	30	1800	42.43	320.73	0.11	0.00
4/5/12	9:37 AM	0.58	35	2100	45.83	320.74	0.12	0.00
4/5/12	9:42 AM	0.67	40	2400	48.99	320.75	0.13	0.01
4/5/12	9:47 AM	0.75	45	2700	51.96	320.75	0.13	0.01
4/5/12	10:02 AM	1.00	60	3600	60.00	320.75	0.13	0.01
4/5/12	10:32 AM	1.50	90	5400	73.48	320.76	0.14	0.01
4/5/12	11:02 AM	2.00	120	7200	84.85	320.81	0.19	0.01
4/5/12	11:32 AM	2.50	150	9000	94.87	320.82	0.20	0.01
4/5/12	12:02 PM	3.00	180	10800	103.92	320.78	0.16	0.01
4/5/12	1:27 PM	4.38	263	15780	125.62	320.81	0.19	0.01
4/5/12	2:02 PM	5.00	300	18000	134.16	320.81	0.19	0.01
4/5/12	3:02 PM	6.00	360	21600	146.97	320.83	0.21	0.01
4/5/12	4:02 PM	7.00	420	25200	158.75	320.84	0.22	0.01
4/5/12	5:02 PM	8.00	480	28800	169.71	320.85	0.23	0.01
4/5/12	6:02 PM	9.00	540	32400	180.00	320.85	0.23	0.01
4/5/12	8:02 PM	11.00	660	39600	199.00	320.89	0.27	0.01
4/5/12	10:43 PM	13.68	821	49260	221.95	320.89	0.27	0.01
4/6/12	12:32 AM	15.50	930	55800	236.22	320.91	0.29	0.01
4/6/12	9:32 AM	24.50	1470	88200	296.98	321.03	0.41	0.02
4/6/12	12:09 PM	27.12	1627	97620	312.44	321.03	0.41	0.02
4/6/12	2:02 PM	29.00	1740	104400	323.11	321.03	0.41	0.02
4/6/12	8:40 PM	35.43	2126	127560	357.16	321.08	0.46	0.02
4/7/12	1:02 AM	40.00	2400	144000	379.47	321.10	0.48	0.02
4/7/12	5:48 AM	56.77	3406	204360	452.06	321.24	0.62	0.02
4/8/12	11:25 AM	74.38	4463	267780	517.47	321.37	0.75	0.03
4/9/12	3:09 PM	102.12	6127	367620	606.32	321.57	0.95	0.04
4/9/12	5:24 PM	104.37	6262	375720	612.96	321.59	0.97	0.04
4/9/12	10:24 PM	109.37	6562	393720	627.47	321.63	1.01	0.04
4/10/12	8:42 AM	119.67	7180	430800	656.35	321.74	1.12	0.04
4/10/12	6:25 PM	129.72	7783	466980	683.36	321.73	1.11	0.04
4/11/12	10:28 AM	145.43	8726	523560	723.57	321.83	1.21	0.05
4/11/12	5:07 PM	152.10	9126	547560	739.97	321.86	1.24	0.05
4/12/12	9:17 AM	168.25	10095	605700	778.27	321.97	1.35	0.05
4/12/12	2:56 PM	173.90	10434	626040	791.23	322.01	1.39	0.05
4/13/12	10:20 AM	193.30	11598	695880	834.19	322.09	1.47	0.06
4/13/12	4:49 PM	199.78	11987	719220	848.07	322.11	1.49	0.06
4/13/12	11:33 PM	206.52	12391	743460	862.24	322.15	1.53	0.06
4/14/12	9:33 AM	216.50	12990	779400	882.84	322.19	1.57	0.06
4/14/12	7:03 PM	226.00	13560	813600	902.00	322.24	1.62	0.06
4/15/12	1:11 PM	244.68	14681	880860	938.54	322.28	1.66	0.06
4/15/12	7:54 PM	250.87	15052	903120	950.33	322.28	1.66	0.06
4/16/12	8:40 AM	275.62	16537	992220	996.10	322.40	1.78	0.07
4/17/12	12:14 PM	292.20	17532	1051920	1025.63	322.45	1.83	0.07
4/17/12	10:09 AM	301.12	18067	1084020	1041.16	322.51	1.89	0.07
4/19/12	10:53 AM	331.85	19911	1194660	1093.01	322.63	2.01	0.08
4/21/12	2:00 PM	388.97	23338	1400280	1183.33	322.78	2.16	0.08
4/22/12	4:02 PM	415.00	24900	1494000	1222.29	322.80	2.18	0.08
4/23/12	8:34 PM	431.53	25892	1553520	1246.40	322.83	2.21	0.09
4/24/12	8:24 AM	455.37	27322	1639320	1280.36	322.88	2.26	0.09
4/25/12	10:47 AM	481.75	28905	1734300	1316.93	322.93	2.31	0.09
4/26/12	8:55 AM	503.88	30233	1813980	1346.84	322.98	2.36	0.09
4/27/12	10:08 AM	529.05	31743	1904580	1380.07	323.09	2.47	0.10
4/28/12	11:06 PM	566.07	33964	2037840	1427.53	323.19	2.57	0.10

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of ANTIHYGRO + KSE 300E Sample C1.3								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:04 AM	0.00	0	0	0.00	320.62	0.00	0.00
4/5/12	9:09 AM	0.08	5	300	17.32	320.67	0.05	0.00
4/5/12	9:14 AM	0.17	10	600	24.49	320.68	0.06	0.00
4/5/12	9:19 AM	0.25	15	900	30.00	320.70	0.08	0.00
4/5/12	9:24 AM	0.33	20	1200	34.64	320.71	0.09	0.00
4/5/12	9:29 AM	0.42	25	1500	38.73	320.71	0.09	0.00
4/5/12	9:34 AM	0.50	30	1800	42.43	320.71	0.09	0.00
4/5/12	9:39 AM	0.58	35	2100	45.83	320.72	0.10	0.00
4/5/12	9:44 AM	0.67	40	2400	48.99	320.72	0.10	0.00
4/5/12	9:49 AM	0.75	45	2700	51.96	320.73	0.11	0.00
4/5/12	10:04 AM	1.00	60	3600	60.00	320.73	0.11	0.00
4/5/12	10:34 AM	1.50	90	5400	73.48	320.76	0.14	0.01
4/5/12	11:04 AM	2.00	120	7200	84.85	320.81	0.19	0.01
4/5/12	11:34 AM	2.50	150	9000	94.87	320.75	0.13	0.01
4/5/12	12:04 PM	3.00	180	10800	103.92	320.77	0.15	0.01
4/5/12	1:28 AM	4.38	263	15780	125.62	320.81	0.19	0.01
4/5/12	2:04 PM	5.00	300	18000	134.16	320.81	0.19	0.01
4/5/12	3:04 PM	6.00	360	21600	146.97	320.83	0.21	0.01
4/5/12	4:04 PM	7.00	420	25200	158.75	320.83	0.21	0.01
4/5/12	5:04 PM	8.00	480	28800	169.71	320.85	0.23	0.01
4/5/12	6:04 PM	9.00	540	32400	180.00	320.85	0.23	0.01
4/5/12	8:04 PM	11.00	660	39600	199.00	320.90	0.28	0.01
4/5/12	10:45 PM	13.68	821	49260	221.95	320.93	0.31	0.01
4/6/12	12:34 AM	15.50	930	55800	236.22	320.94	0.32	0.01
4/6/12	9:34 AM	24.50	1470	88200	296.98	321.08	0.46	0.02
4/6/12	12:11 PM	27.12	1627	97620	312.44	321.08	0.46	0.02
4/6/12	2:04 PM	29.00	1740	104400	323.11	321.08	0.46	0.02
4/6/12	8:42 PM	35.43	2126	127560	357.16	321.10	0.48	0.02
4/7/12	1:04 AM	40.00	2400	144000	379.47	321.10	0.48	0.02
4/7/12	5:50 AM	56.77	3406	204360	452.06	321.23	0.61	0.02
4/8/12	11:27 AM	74.38	4463	267780	517.47	321.33	0.71	0.03
4/9/12	3:11 PM	102.12	6127	367620	606.32	321.47	0.85	0.03
4/9/12	5:26 PM	104.37	6262	375720	612.96	321.47	0.85	0.03
4/9/12	10:26 PM	109.37	6562	393720	627.47	321.49	0.87	0.03
4/10/12	8:44 AM	119.67	7180	430800	656.35	321.54	0.92	0.04
4/10/12	6:27 PM	129.72	7783	466980	683.36	321.59	0.97	0.04
4/11/12	10:30 AM	145.43	8726	523560	723.57	321.65	1.03	0.04
4/11/12	5:09 PM	152.10	9126	547560	739.97	321.67	1.05	0.04
4/12/12	9:19 AM	168.25	10095	605700	778.27	321.75	1.13	0.04
4/12/12	2:58 PM	173.90	10434	626040	791.23	321.80	1.18	0.05
4/13/12	10:22 AM	193.30	11598	695880	834.19	321.83	1.21	0.05
4/13/12	4:51 PM	199.78	11987	719220	848.07	321.86	1.24	0.05
4/13/12	11:35 PM	206.52	12391	743460	862.24	321.93	1.31	0.05
4/14/12	9:35 AM	216.50	12990	779400	882.84	321.93	1.31	0.05
4/14/12	7:03 PM	226.00	13560	813600	902.00	321.96	1.34	0.05
4/15/12	1:11 PM	244.68	14681	880860	938.54	321.98	1.36	0.05
4/15/12	7:54 PM	250.87	15052	903120	950.33	322.02	1.40	0.05
4/16/12	8:40 AM	275.62	16537	992220	996.10	322.10	1.48	0.06
4/17/12	12:14 PM	292.20	17532	1051920	1025.63	322.15	1.53	0.06
4/17/12	10:09 AM	301.12	18067	1084020	1041.16	322.19	1.57	0.06
4/19/12	10:53 AM	331.85	19911	1194660	1093.01	322.35	1.73	0.07
4/21/12	2:00 PM	388.97	23338	1400280	1183.33	322.45	1.83	0.07
4/22/12	4:02 PM	415.00	24900	1494000	1222.29	322.49	1.87	0.07
4/23/12	8:34 PM	431.53	25892	1553520	1246.40	322.53	1.91	0.07
4/24/12	8:24 AM	455.37	27322	1639320	1280.36	322.55	1.93	0.07
4/25/12	10:47 AM	481.75	28905	1734300	1316.93	322.63	2.01	0.08
4/26/12	8:55 AM	503.88	30233	1813980	1346.84	322.65	2.03	0.08
4/27/12	10:08 AM	529.05	31743	1904580	1380.07	322.75	2.13	0.08
4/28/12	11:06 PM	566.07	33964	2037840	1427.53	322.76	2.14	0.08

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Capillary Absorption of OH100 Sample D1.3								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:04 AM	0.00	0	0	0.00	329.34	0.00	0.000
4/5/12	9:09 AM	0.08	5	300	17.32	329.38	0.04	0.002
4/5/12	9:14 AM	0.17	10	600	24.49	329.40	0.06	0.002
4/5/12	9:19 AM	0.25	15	900	30.00	329.41	0.07	0.003
4/5/12	9:24 AM	0.33	20	1200	34.64	329.44	0.10	0.004
4/5/12	9:29 AM	0.42	25	1500	38.73	329.46	0.12	0.005
4/5/12	9:34 AM	0.50	30	1800	42.43	329.46	0.12	0.005
4/5/12	9:39 AM	0.58	35	2100	45.83	329.48	0.14	0.005
4/5/12	9:44 AM	0.67	40	2400	48.99	329.48	0.14	0.005
4/5/12	9:49 AM	0.75	45	2700	51.96	329.48	0.14	0.005
4/5/12	10:04 AM	1.00	60	3600	60.00	329.48	0.14	0.005
4/5/12	10:34 AM	1.50	90	5400	73.48	329.48	0.14	0.005
4/5/12	11:04 AM	2.00	120	7200	84.85	329.55	0.21	0.008
4/5/12	11:34 AM	2.50	150	9000	94.87	329.56	0.22	0.009
4/5/12	12:04 PM	3.00	180	10800	103.92	329.52	0.18	0.007
4/5/12	1:28 PM	4.38	263	15780	125.62	329.57	0.23	0.009
4/5/12	2:04 PM	5.00	300	18000	134.16	329.59	0.25	0.010
4/5/12	3:04 PM	6.00	360	21600	146.97	329.61	0.27	0.010
4/5/12	4:04 PM	7.00	420	25200	158.75	329.62	0.28	0.011
4/5/12	5:04 PM	8.00	480	28800	169.71	329.64	0.30	0.012
4/5/12	6:04 PM	9.00	540	32400	180.00	329.66	0.32	0.012
4/5/12	8:04 PM	11.00	660	39600	199.00	329.70	0.36	0.014
4/5/12	12:34 AM	15.50	930	55800	236.22	329.70	0.36	0.014
4/6/12	9:34 AM	24.50	1470	88200	296.98	329.81	0.47	0.018
4/6/12	12:11 PM	27.12	1627	97620	312.44	329.84	0.50	0.019
4/6/12	2:04 PM	29.00	1740	104400	323.11	329.85	0.51	0.020
4/6/12	8:42 PM	35.43	2126	127560	357.16	329.86	0.52	0.020
4/7/12	1:04 AM	40.00	2400	144000	379.47	329.87	0.53	0.021
4/7/12	5:50 AM	56.77	3406	204360	452.06	330.00	0.66	0.026
4/8/12	11:27 AM	74.38	4463	267780	517.47	330.08	0.74	0.029
4/9/12	3:11 PM	102.12	6127	367620	606.32	330.27	0.93	0.036
4/9/12	5:26 PM	104.37	6262	375720	612.96	330.27	0.93	0.036
4/9/12	10:26 PM	109.37	6562	393720	627.47	330.27	0.93	0.036
4/10/12	8:44 AM	119.67	7180	430800	656.35	330.32	0.98	0.038
4/10/12	6:27 PM	129.72	7783	466980	683.36	330.37	1.03	0.040
4/11/12	10:30 AM	145.43	8726	523560	723.57	330.44	1.10	0.043
4/11/12	5:09 PM	152.10	9126	547560	739.97	330.44	1.10	0.043
4/12/12	9:19 AM	168.25	10095	605700	778.27	330.51	1.17	0.045
4/12/12	2:58 PM	173.90	10434	626040	791.23	330.50	1.16	0.045
4/13/12	10:22 AM	193.30	11598	695880	834.19	330.62	1.28	0.050
4/13/12	4:51 PM	199.78	11987	719220	848.07	330.61	1.27	0.049
4/13/12	11:35 PM	206.52	12391	743460	862.24	330.63	1.29	0.050
4/14/12	9:35 AM	216.50	12990	779400	882.84	330.65	1.31	0.051
4/14/12	7:04 PM	226.00	13560	813600	902.00	330.70	1.36	0.053
4/15/12	1:14 PM	244.68	14681	880860	938.54	330.70	1.36	0.053
4/15/12	7:55 PM	250.87	15052	903120	950.33	330.74	1.40	0.054
4/16/12	8:41 AM	275.62	16537	992220	996.10	330.80	1.46	0.057
4/17/12	12:15 PM	292.20	17532	1051920	1025.63	330.89	1.55	0.060
4/17/12	10:10 AM	301.12	18067	1084020	1041.16	330.92	1.58	0.061
4/18/12	11:23 AM	314.33	18860	1131600	1063.77	330.93	1.59	0.062
4/19/12	10:55 AM	331.85	19911	1194660	1093.01	331.00	1.66	0.064
4/21/12	2:01 PM	388.97	23338	1400280	1183.33	331.17	1.83	0.071
4/22/12	4:03 PM	415.00	24900	1494000	1222.29	331.19	1.85	0.072
4/23/12	8:35 PM	431.53	25892	1553520	1246.40	331.21	1.87	0.072
4/24/12	8:25 AM	455.37	27322	1639320	1280.36	331.29	1.95	0.076
4/25/12	10:48 AM	481.75	28905	1734300	1316.93	331.36	2.02	0.078
4/26/12	8:56 AM	503.88	30233	1813980	1346.84	331.37	2.03	0.079
4/27/12	10:08 AM	529.05	31743	1904580	1380.07	331.43	2.09	0.081
4/28/12	2:21 AM	545.28	32717	1963020	1401.08	331.47	2.13	0.083
4/28/12	11:07 PM	566.07	33964	2037840	1427.53	331.54	2.20	0.085
4/29/12	12:38 PM	579.40	34764	2085840	1444.24	331.55	2.21	0.086
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	331.55	2.21	0.086

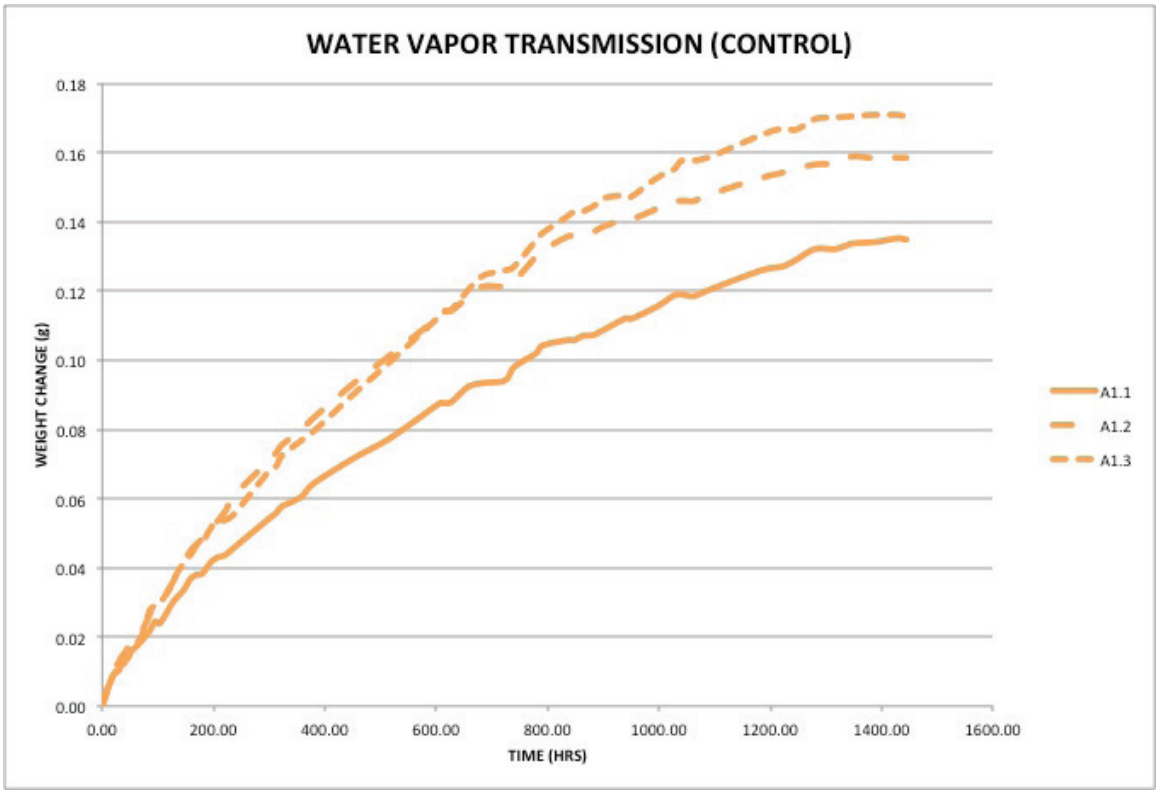
APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

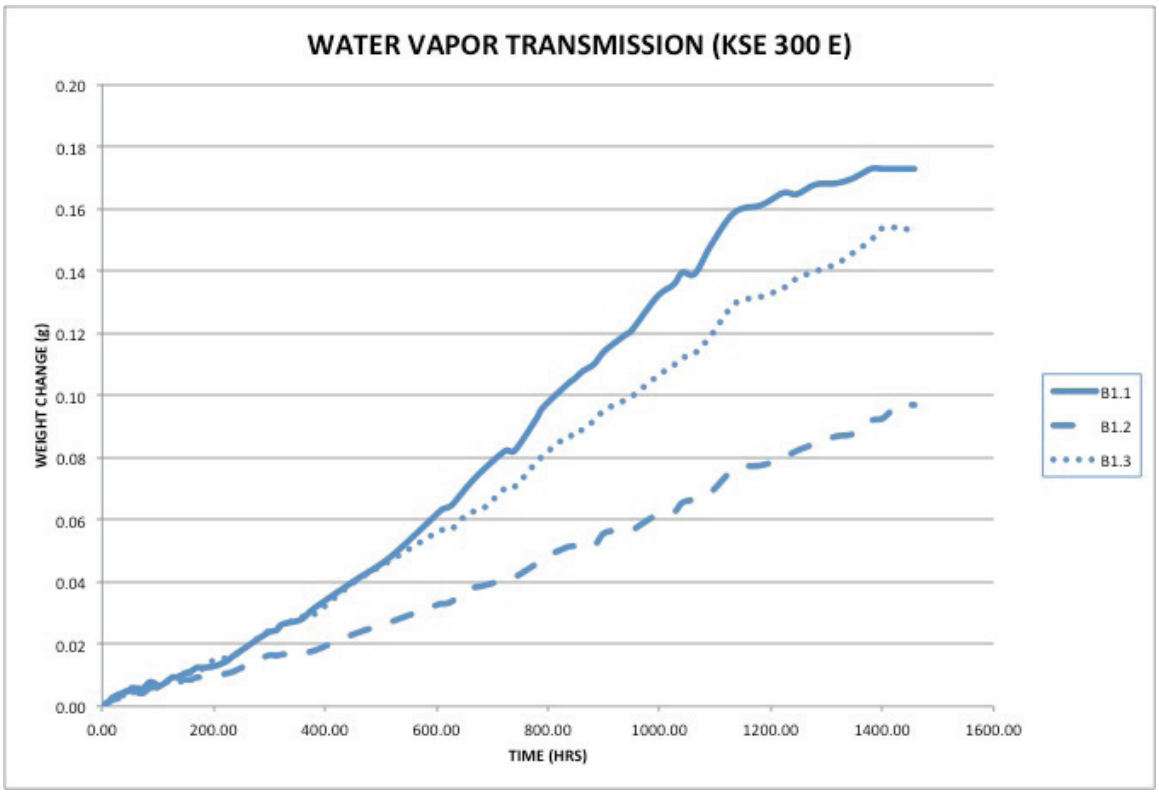
Capillary Absorption of OH100 Sample D1.2								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:04 AM	0.00	0	0	0.00	329.49	0.00	0.000
4/5/12	9:09 AM	0.08	5	300	17.32	329.61	0.12	0.005
4/5/12	9:14 AM	0.17	10	600	24.49	329.51	0.02	0.001
4/5/12	9:19 AM	0.25	15	900	30.00	329.56	0.07	0.003
4/5/12	9:24 AM	0.33	20	1200	34.64	329.57	0.08	0.003
4/5/12	9:29 AM	0.42	25	1500	38.73	329.57	0.08	0.003
4/5/12	9:34 AM	0.50	30	1800	42.43	329.58	0.09	0.003
4/5/12	9:39 AM	0.58	35	2100	45.83	329.61	0.12	0.005
4/5/12	9:44 AM	0.67	40	2400	48.99	329.61	0.12	0.005
4/5/12	9:49 AM	0.75	45	2700	51.96	329.62	0.13	0.005
4/5/12	10:04 AM	1.00	60	3600	60.00	329.61	0.12	0.005
4/5/12	10:34 AM	1.50	90	5400	73.48	329.60	0.11	0.004
4/5/12	11:04 AM	2.00	120	7200	84.85	329.67	0.18	0.007
4/5/12	11:34 AM	2.50	150	9000	94.87	329.69	0.20	0.008
4/5/12	12:04 PM	3.00	180	10800	103.92	329.62	0.13	0.005
4/5/12	1:28 PM	4.38	263	15780	125.62	329.64	0.15	0.006
4/5/12	2:04 PM	5.00	300	18000	134.16	329.65	0.16	0.006
4/5/12	3:04 PM	6.00	360	21600	146.97	329.66	0.17	0.007
4/5/12	4:04 PM	7.00	420	25200	158.75	329.68	0.19	0.007
4/5/12	5:04 PM	8.00	480	28800	169.71	329.70	0.21	0.008
4/5/12	6:04 PM	9.00	540	32400	180.00	329.70	0.21	0.008
4/5/12	8:04 PM	11.00	660	39600	199.00	329.71	0.22	0.009
4/5/12	12:34 AM	15.50	930	55800	236.22	329.71	0.22	0.009
4/6/12	9:34 AM	24.50	1470	88200	296.98	329.77	0.28	0.011
4/6/12	12:11 PM	27.12	1627	97620	312.44	329.79	0.30	0.012
4/6/12	2:04 PM	29.00	1740	104400	323.11	329.79	0.30	0.012
4/6/12	8:42 PM	35.43	2126	127560	357.16	329.81	0.32	0.012
4/7/12	1:04 AM	40.00	2400	144000	379.47	329.82	0.33	0.013
4/7/12	5:50 AM	56.77	3406	204360	452.06	329.86	0.37	0.014
4/8/12	11:27 AM	74.38	4463	267780	517.47	329.89	0.40	0.016
4/9/12	3:11 PM	102.12	6127	367620	606.32	329.95	0.46	0.018
4/9/12	5:26 PM	104.37	6262	375720	612.96	329.97	0.48	0.019
4/9/12	10:26 PM	109.37	6562	393720	627.47	329.97	0.48	0.019
4/10/12	8:44 AM	119.67	7180	430800	656.35	330.00	0.51	0.020
4/10/12	6:27 PM	129.72	7783	466980	683.36	330.01	0.52	0.020
4/11/12	10:30 AM	145.43	8726	523560	723.57	330.04	0.55	0.021
4/11/12	5:09 PM	152.10	9126	547560	739.97	330.06	0.57	0.022
4/12/12	9:19 AM	168.25	10095	605700	778.27	330.07	0.58	0.022
4/12/12	2:58 PM	173.90	10434	626040	791.23	330.07	0.58	0.022
4/13/12	10:22 AM	193.30	11598	695880	834.19	330.13	0.64	0.025
4/13/12	4:51 PM	199.78	11987	719220	848.07	330.10	0.61	0.024
4/13/12	11:35 PM	206.52	12391	743460	862.24	330.14	0.65	0.025
4/14/12	9:35 AM	216.50	12990	779400	882.84	330.14	0.65	0.025
4/14/12	7:04 PM	226.00	13560	813600	902.00	330.14	0.65	0.025
4/15/12	1:14 PM	244.68	14681	880860	938.54	330.18	0.69	0.027
4/15/12	7:55 PM	250.87	15052	903120	950.33	330.16	0.67	0.026
4/16/12	8:41 AM	275.62	16537	992220	996.10	330.20	0.71	0.028
4/17/12	12:15 PM	292.20	17532	1051920	1025.63	330.23	0.74	0.029
4/17/12	10:10 AM	301.12	18067	1084020	1041.16	330.26	0.77	0.030
4/18/12	11:23 AM	314.33	18860	1131600	1063.77	330.24	0.75	0.029
4/19/12	10:55 AM	331.85	19911	1194660	1093.01	330.28	0.79	0.031
4/21/12	2:01 PM	388.97	23338	1400280	1183.33	330.38	0.89	0.034
4/22/12	4:03 PM	415.00	24900	1494000	1222.29	330.37	0.88	0.034
4/23/12	8:35 PM	431.53	25892	1553520	1246.40	330.40	0.91	0.035
4/24/12	8:25 AM	455.37	27322	1639320	1280.36	330.40	0.91	0.035
4/25/12	10:48 AM	481.75	28905	1734300	1316.93	330.45	0.96	0.037
4/26/12	8:56 AM	503.88	30233	1813980	1346.84	330.47	0.98	0.038
4/27/12	10:08 AM	529.05	31743	1904580	1380.07	330.50	1.01	0.039
4/28/12	2:21 AM	545.28	32717	1963020	1401.08	330.51	1.02	0.040
4/28/12	11:07 PM	566.07	33964	2037840	1427.53	330.53	1.04	0.040
4/29/12	12:38 PM	579.40	34764	2085840	1444.24	330.53	1.04	0.040
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	330.53	1.04	0.040

APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

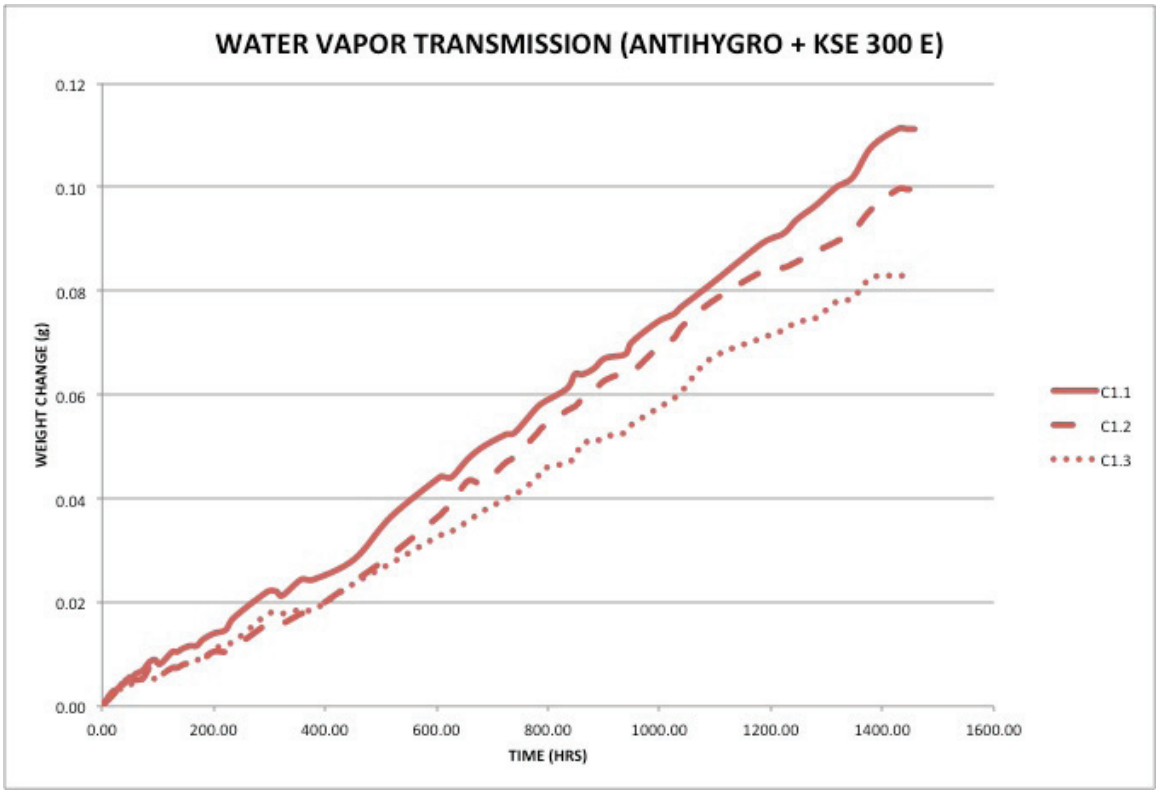
Capillary Absorption of OH100 Sample D1.3								
Date	Actual time	time (hr)	Time (m)	Time (s)	Sq Rt Time (s^1/2)	Mass (g)	Ut (g)	M1 (g/cm^2)
4/5/12	9:04 AM	0.00	0	0	0.00	329.34	0.00	0.000
4/5/12	9:09 AM	0.08	5	300	17.32	329.38	0.04	0.002
4/5/12	9:14 AM	0.17	10	600	24.49	329.40	0.06	0.002
4/5/12	9:19 AM	0.25	15	900	30.00	329.41	0.07	0.003
4/5/12	9:24 AM	0.33	20	1200	34.64	329.44	0.10	0.004
4/5/12	9:29 AM	0.42	25	1500	38.73	329.46	0.12	0.005
4/5/12	9:34 AM	0.50	30	1800	42.43	329.46	0.12	0.005
4/5/12	9:39 AM	0.58	35	2100	45.83	329.48	0.14	0.005
4/5/12	9:44 AM	0.67	40	2400	48.99	329.48	0.14	0.005
4/5/12	9:49 AM	0.75	45	2700	51.96	329.48	0.14	0.005
4/5/12	10:04 AM	1.00	60	3600	60.00	329.48	0.14	0.005
4/5/12	10:34 AM	1.50	90	5400	73.48	329.48	0.14	0.005
4/5/12	11:04 AM	2.00	120	7200	84.85	329.55	0.21	0.008
4/5/12	11:34 AM	2.50	150	9000	94.87	329.56	0.22	0.009
4/5/12	12:04 PM	3.00	180	10800	103.92	329.52	0.18	0.007
4/5/12	1:28 PM	4.38	263	15780	125.62	329.57	0.23	0.009
4/5/12	2:04 PM	5.00	300	18000	134.16	329.59	0.25	0.010
4/5/12	3:04 PM	6.00	360	21600	146.97	329.61	0.27	0.010
4/5/12	4:04 PM	7.00	420	25200	158.75	329.62	0.28	0.011
4/5/12	5:04 PM	8.00	480	28800	169.71	329.64	0.30	0.012
4/5/12	6:04 PM	9.00	540	32400	180.00	329.66	0.32	0.012
4/5/12	8:04 PM	11.00	660	39600	199.00	329.70	0.36	0.014
4/5/12	12:34 AM	15.50	930	55800	236.22	329.70	0.36	0.014
4/6/12	9:34 AM	24.50	1470	88200	296.98	329.81	0.47	0.018
4/6/12	12:11 PM	27.12	1627	97620	312.44	329.84	0.50	0.019
4/6/12	2:04 PM	29.00	1740	104400	323.11	329.85	0.51	0.020
4/6/12	8:42 PM	35.43	2126	127560	357.16	329.86	0.52	0.020
4/7/12	1:04 AM	40.00	2400	144000	379.47	329.87	0.53	0.021
4/7/12	5:50 AM	56.77	3406	204360	452.06	330.00	0.66	0.026
4/8/12	11:27 AM	74.38	4463	267780	517.47	330.08	0.74	0.029
4/9/12	3:11 PM	102.12	6127	367620	606.32	330.27	0.93	0.036
4/9/12	5:26 PM	104.37	6262	375720	612.96	330.27	0.93	0.036
4/9/12	10:26 PM	109.37	6562	393720	627.47	330.27	0.93	0.036
4/10/12	8:44 AM	119.67	7180	430800	656.35	330.32	0.98	0.038
4/10/12	6:27 PM	129.72	7783	466980	683.36	330.37	1.03	0.040
4/11/12	10:30 AM	145.43	8726	523560	723.57	330.44	1.10	0.043
4/11/12	5:09 PM	152.10	9126	547560	739.97	330.44	1.10	0.043
4/12/12	9:19 AM	168.25	10095	605700	778.27	330.51	1.17	0.045
4/12/12	2:58 PM	173.90	10434	626040	791.23	330.50	1.16	0.045
4/13/12	10:22 AM	193.30	11598	695880	834.19	330.62	1.28	0.050
4/13/12	4:51 PM	199.78	11987	719220	848.07	330.61	1.27	0.049
4/13/12	11:35 PM	206.52	12391	743460	862.24	330.63	1.29	0.050
4/14/12	9:35 AM	216.50	12990	779400	882.84	330.65	1.31	0.051
4/14/12	7:04 PM	226.00	13560	813600	902.00	330.70	1.36	0.053
4/15/12	1:14 PM	244.68	14681	880860	938.54	330.70	1.36	0.053
4/15/12	7:55 PM	250.87	15052	903120	950.33	330.74	1.40	0.054
4/16/12	8:41 AM	275.62	16537	992220	996.10	330.80	1.46	0.057
4/17/12	12:15 PM	292.20	17532	1051920	1025.63	330.89	1.55	0.060
4/17/12	10:10 AM	301.12	18067	1084020	1041.16	330.92	1.58	0.061
4/18/12	11:23 AM	314.33	18860	1131600	1063.77	330.93	1.59	0.062
4/19/12	10:55 AM	331.85	19911	1194660	1093.01	331.00	1.66	0.064
4/21/12	2:01 PM	388.97	23338	1400280	1183.33	331.17	1.83	0.071
4/22/12	4:03 PM	415.00	24900	1494000	1222.29	331.19	1.85	0.072
4/23/12	8:35 PM	431.53	25892	1553520	1246.40	331.21	1.87	0.072
4/24/12	8:25 AM	455.37	27322	1639320	1280.36	331.29	1.95	0.076
4/25/12	10:48 AM	481.75	28905	1734300	1316.93	331.36	2.02	0.078
4/26/12	8:56 AM	503.88	30233	1813980	1346.84	331.37	2.03	0.079
4/27/12	10:08 AM	529.05	31743	1904580	1380.07	331.43	2.09	0.081
4/28/12	2:21 AM	545.28	32717	1963020	1401.08	331.47	2.13	0.083
4/28/12	11:07 PM	566.07	33964	2037840	1427.53	331.54	2.20	0.085
4/29/12	12:38 PM	579.40	34764	2085840	1444.24	331.55	2.21	0.086
4/29/12	11:06 PM	590.10	35406	2124360	1457.52	331.55	2.21	0.086

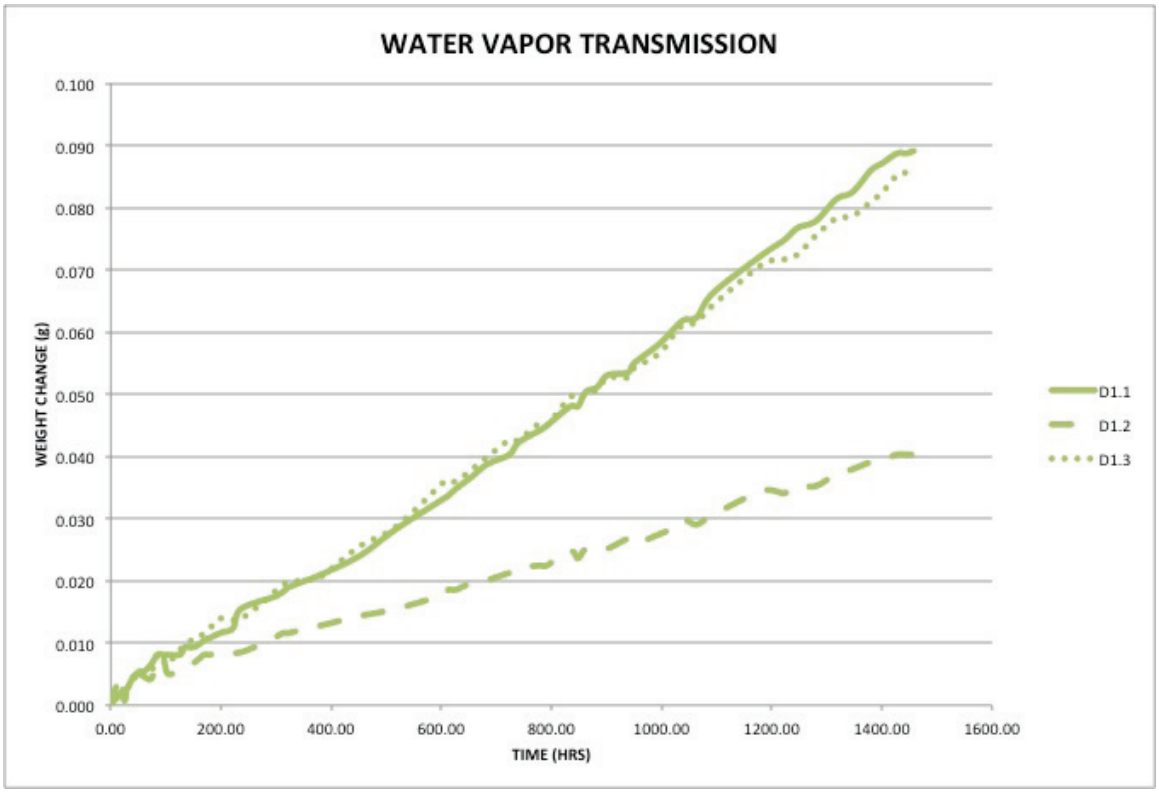
APPENDIX B: CAPILLARY ABSORPTION TESTING DATA





APPENDIX B: CAPILLARY ABSORPTION TESTING DATA





APPENDIX B: CAPILLARY ABSORPTION TESTING DATA

Calculations for Capillary Absorption Coefficient												
	A1.1	A1.2	A1.3	B1.1	B1.2	B1.3	C1.1	C1.2	C1.3	D1.1	D1.2	D1.3
Capillary Absorption Coefficient	2.30E-04	2.42E-04	2.53E-04	5.90E-05	5.65E-05	9.47E-05	7.39E-05	6.93E-05	5.76E-05	5.60E-05	2.54E-05	5.48E-05
Correlation Factor	0.993	0.996	0.997	0.982	0.996	0.995	0.999	0.996	0.998	0.998	0.996	0.997

Calculations for Total Immersion												
	A1.1	A1.2	A1.3	B1.1	B1.2	B1.3	C1.1	C1.2	C1.3	D1.1	D1.2	D1.3
Wdry (g)	318.14	326.78	318.8	317.16	320.83	323.48	324.97	320.62	320.62	317.86	329.49	329.34
Wmax (g)	321.63	330.84	323.12	322.13	323.9	327.88	328.27	323.58	323.31	320.74	331.25	332.01
Uo (Wmax- dry) (g)	3.49	4.06	4.32	4.97	3.07	4.40	3.30	2.96	2.69	2.88	1.76	2.67
Imbibition Capacity	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
WAC (%)	1.10	1.24	1.36	1.57	0.96	1.36	1.02	0.92	0.84	0.91	0.53	0.81
Vop (cm^3)	3.49	4.06	4.32	4.97	3.07	4.40	3.30	2.96	2.69	2.88	1.76	2.67
Vs (cm^3)	125	125	125	125	125	125	125	125	125	125	125	125
% Open Porosity	2.8	3.2	3.5	4.0	2.5	3.5	2.6	2.4	2.2	2.3	1.4	2.1

APPENDIX C:

WATER VAPOR TRANSMISSION TESTING DATA

APPENDIX E: WATER VAPOR TRANSMISSION TESTING DATA

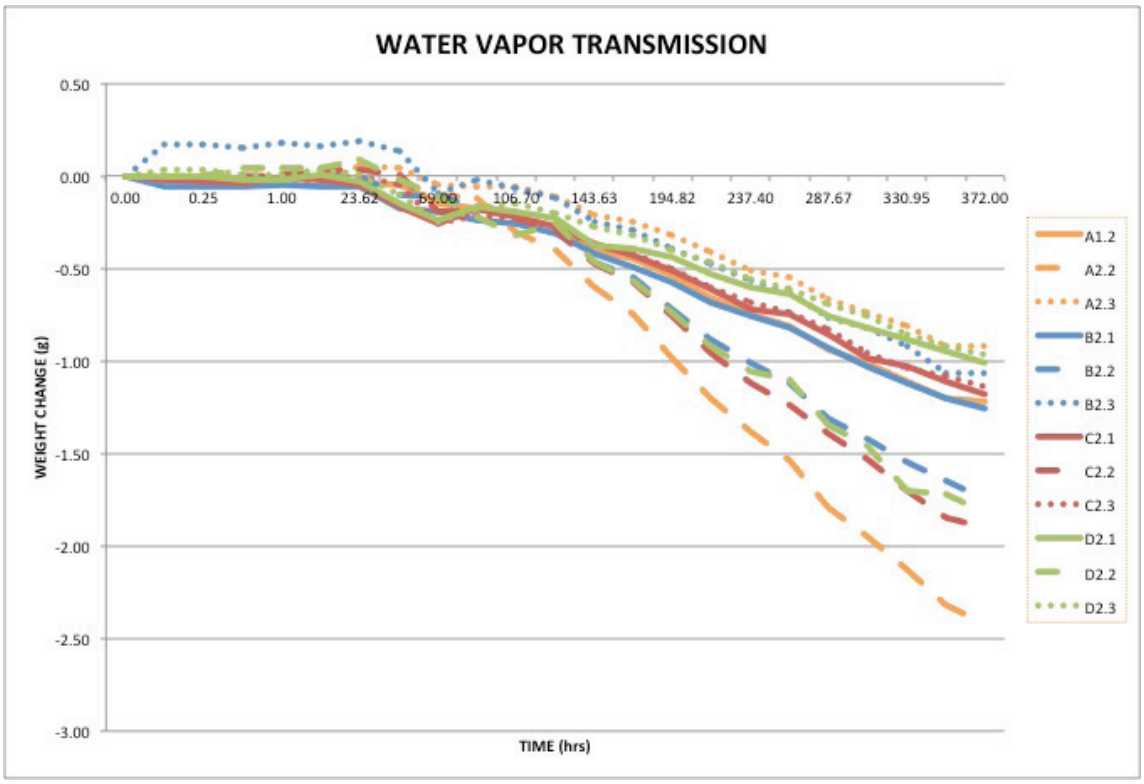
WATER VAPOR TRANSMISSION TESTING DATA MCNABB SAAN THESIS 2012

DATE	T (F)	%RH	TIME ELAPSED	MASS A2.1 (g)	MASS A2.2 (g)	MASS A2.3 (g)	MASS B2.1 (g)	MASS B2.2 (g)	MASS B2.3 (g)	MASS C2.1 (g)	MASS C2.2 (g)	MASS C2.3 (g)	MASS D2.1 (g)	MASS D2.2 (g)	MASS D2.3 (g)
4/13/12	25.3	42	0.00	586.28	512.51	603.95	586.86	545.57	593.41	620.73	606.28	584.21	620.39	605.13	583.77
4/13/12	25.3	42	0.08	586.26	512.51	603.94	565.80	545.57	593.58	620.71	606.28	584.21	620.39	605.13	583.80
4/13/12	25.3	37	0.25	586.27	512.52	603.95	565.80	545.56	593.58	620.70	606.28	584.18	620.39	605.13	583.80
4/13/12	25.3	37	0.50	586.27	512.52	603.92	565.80	545.57	593.56	620.69	606.27	584.19	620.37	605.17	583.78
4/13/12	25.3	52	1.00	586.27	512.51	603.92	565.81	545.56	593.59	620.72	606.29	584.21	620.37	605.17	583.78
4/13/12	25.2	56	3.30	586.27	512.50	603.92	565.80	545.57	593.57	620.71	606.31	584.22	620.40	605.17	583.80
4/14/12	25.2	60	23.62	586.24	512.57	604.00	565.80	545.57	593.60	620.68	606.31	582.21	620.36	605.22	583.78
4/14/12	25.1	46	50.00	586.23	512.47	603.99	565.68	545.47	593.54	620.56	606.29	584.16	620.24	605.11	583.67
4/15/12	26.2	49	69.00	586.13	512.41	603.90	565.67	545.46	593.32	620.47	606.09	583.95	620.15	604.92	583.52
4/16/12	27.0	53	96.00	586.10	512.39	603.89	565.62	545.40	593.39	620.55	606.10	584.00	620.22	604.97	583.59
4/17/12	26.2	49	106.70	586.06	512.21	603.89	565.60	545.35	593.34	620.51	606.05	583.98	620.20	604.81	583.62
4/18/12	27.9	54	119.30	586.00	512.11	603.84	565.55	545.27	593.29	620.45	605.99	583.93	620.16	604.87	583.57
4/19/12	26.7	48	143.63	585.88	511.91	603.74	565.44	545.10	593.16	620.36	605.80	583.83	620.01	604.66	583.49
4/20/12	25.7	49	163.80	585.83	511.76	603.70	565.37	545.02	593.12	620.30	605.70	583.79	620.00	604.56	583.45
4/21/12	27.3	49	194.82	585.74	511.53	603.63	565.28	544.85	593.02	620.22	605.52	583.71	619.95	604.39	583.37
4/22/12	26.8	51	220.85	585.62	511.31	603.54	565.18	544.69	592.93	620.12	605.32	583.61	619.86	604.21	583.30
4/23/12	25.6	50	237.40	585.53	511.13	603.44	565.10	544.56	592.84	620.01	605.16	583.53	619.79	604.07	583.21
4/24/12	24.5	51	261.30	585.47	510.97	603.40	565.04	544.45	592.78	619.98	605.04	583.47	619.75	604.97	583.16
4/25/12	24.6	50	287.67	585.34	510.72	603.28	564.93	544.26	592.64	619.87	604.89	583.38	619.63	603.78	583.08
4/26/12	25.6	51	309.78	585.27	510.56	603.21	565.83	544.15	592.59	619.75	604.75	583.25	619.57	603.67	583.01
4/27/12	24.4	52	330.95	585.17	510.72	603.14	565.74	544.02	592.49	619.70	604.58	583.17	619.51	603.43	582.91
4/28/12	25.0	52	355.42	585.08	510.19	603.03	565.66	543.92	592.34	619.62	604.43	583.13	619.44	603.41	582.85
4/29/12	24.4	51	372.00	585.06	510.09	603.03	565.60	543.82	592.34	619.55	604.38	583.07	619.38	603.31	582.80

WATER VAPOR TRANSMISSION ALL SAMPLES

	Sample										
Parameter	**A2.1**	**A2.2**	**A2.3**	**B2.1**	**B2.2**	**B2.3**	**C2.1**	**C2.2**	**C2.3**	**D2.1**	**D2.2**	**D2.3**
Length 1 (in)	2.00	2.00	1.99	2.00	2.03	2.00	2.00	2.08	2.00	2.00	2.00	2.00
Length 2 (in)	2.00	2.00	1.80	2.00	1.98	2.03	2.03	1.98	2.03	1.98	1.98	2.00
Length 3 (in)	2.00	2.01	19.25	2.02	2.02	2.00	2.00	2.03	2.00	2.00	2.00	2.00
Mcoupon (g)	57.81	57.99	60.07	65.12	60.19	63.15	61.78	57.78	60.03	55.97	60.33	58.96
Mcoupon+tape (g)	58.86	59.06	61.14	66.35	61.35	64.29	62.91	58.91	61.13	57.03	61.44	60.02
Mcontainer (g)	474.48	399.73	489.90	475.56	431.09	445.95	503.25	492.70	468.32	509.88	491.87	470.00
Mcontainer+wtr (g)	525.31	450.75	540.26	525.97	481.76	496.53	554.12	543.66	519.48	560.77	541.62	521.18
M Final (g)	586.28	512.52	603.94	565.86	545.57	593.41	620.73	606.28	584.21	620.39	605.13	585.77

APPENDIX E: WATER VAPOR TRANSMISSION TESTING DATA



APPENDIX D:

DRYING INDEX TESTING DATA

APPENDIX E: DRYING INDEX TESTING DATA

Drying Imdex A1.1							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	10:23 AM	0.00	0.00	321.77	3.63	2.90E-02	3.33E-04
4/30/12	10:26 AM	0.05	3.00	321.63	3.49	2.79E-02	3.33E-04
4/30/12	10:29 AM	0.10	6.00	321.52	3.38	2.70E-02	3.33E-04
4/30/12	10:32 AM	0.15	9.00	321.46	3.32	2.66E-02	8.00E-03
4/30/12	10:35 AM	0.20	12.00	321.41	3.27	2.62E-02	9.60E-03
4/30/12	10:38 AM	0.25	15.00	321.35	3.21	2.57E-02	1.92E-03
4/30/12	10:43 AM	0.33	20.00	321.33	3.19	2.55E-02	2.88E-03
4/30/12	10:48 AM	0.42	25.00	321.30	3.16	2.53E-02	1.92E-03
4/30/12	10:53 AM	0.50	30.00	321.28	3.14	2.51E-02	3.36E-03
4/30/12	11:03 AM	0.67	40.00	321.21	3.07	2.46E-02	9.60E-04
4/30/12	11:13 AM	0.83	50.00	321.19	3.05	2.44E-02	9.60E-04
4/30/12	11:23 AM	1.00	60.00	321.17	3.03	2.42E-02	9.60E-04
4/30/12	11:33 AM	1.17	70.00	321.15	3.01	2.41E-02	9.60E-04
4/30/12	11:43 AM	1.33	80.00	321.13	2.99	2.39E-02	4.80E-04
4/30/12	11:53 AM	1.50	90.00	321.12	2.98	2.38E-02	6.40E-04
4/30/12	12:08 PM	1.75	105.00	321.10	2.96	2.37E-02	6.40E-04
4/30/12	12:23 PM	2.00	120.00	321.08	2.94	2.35E-02	6.40E-04
4/30/12	12:38 PM	2.25	135.00	321.06	2.92	2.34E-02	9.60E-04
4/30/12	12:53 PM	2.50	150.00	321.03	2.89	2.31E-02	4.80E-04
4/30/12	1:23 PM	3.00	180.00	321.00	2.86	2.29E-02	3.20E-04
4/30/12	2:23 PM	4.00	330.00	320.96	2.82	2.26E-02	3.20E-04
4/30/12	2:53 PM	4.50	390.00	320.94	2.80	2.24E-02	2.40E-04
4/30/12	3:53 PM	5.50	330.00	320.91	2.77	2.22E-02	3.20E-04
4/30/12	4:53 PM	6.50	390.00	320.87	2.73	2.18E-02	2.40E-04
4/30/12	5:53 PM	7.50	450.00	320.84	2.70	2.16E-02	2.40E-04
4/30/12	6:53 PM	8.50	510.00	320.81	2.67	2.14E-02	8.00E-05
4/30/12	7:53 PM	9.50	570.00	320.80	2.66	2.13E-02	1.60E-04
5/1/12	6:24 AM	19.02	1141.00	320.61	2.47	1.98E-02	8.18E-05
5/1/12	8:20 AM	21.95	1317.00	320.58	2.44	1.95E-02	4.63E-05
5/1/12	1:31 PM	27.13	1628.00	320.55	2.41	1.93E-02	1.19E-04
5/1/12	5:18 PM	29.83	1790.00	320.51	2.37	1.90E-02	1.01E-04
5/2/12	1:12 AM	37.75	2265.00	320.41	2.27	1.82E-02	4.43E-05
5/2/12	8:25 AM	44.97	2698.00	320.37	2.23	1.78E-02	8.57E-05
5/2/12	2:01 PM	50.57	3034.00	320.31	2.17	1.74E-02	4.16E-07
5/2/12	11:01 PM	59.57	3574.00	320.30	2.16	1.73E-02	4.16E-07
5/3/12	10:46 AM	72.40	4344.00	320.27	2.13	1.70E-02	4.16E-07
5/4/12	2:21 AM	86.90	5214.00	320.17	2.03	1.62E-02	4.16E-07
5/4/12	2:30 PM	99.03	5942.00	320.15	2.01	1.61E-02	4.16E-07
5/7/12	3:45 PM	172.33	10340.00	319.94	1.80	1.44E-02	4.16E-07
5/8/12	10:35 AM	191.12	11467.00	319.88	1.74	1.39E-02	4.16E-07

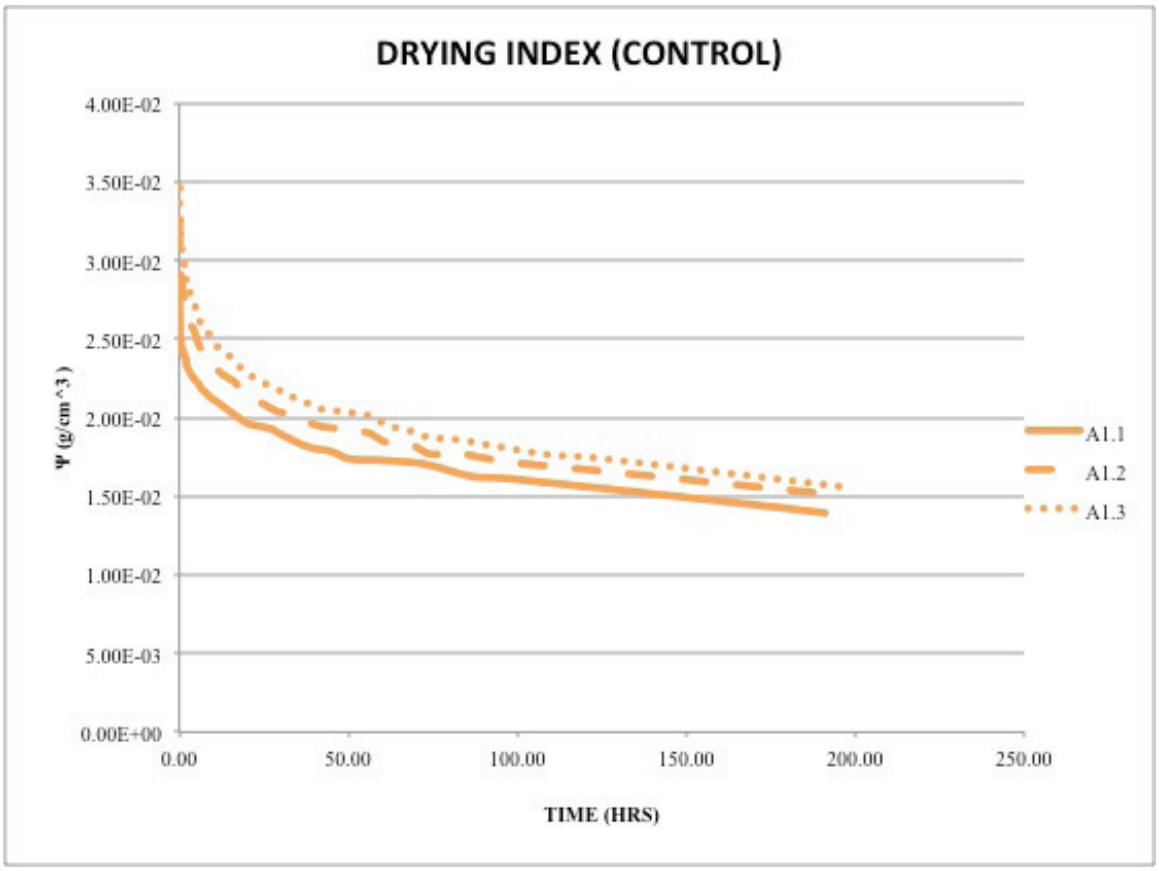
APPENDIX E: DRYING INDEX TESTING DATA

Drying Index A1.2							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	11:40 AM	0.00	0.00	330.84	4.06	3.25E-02	2.24E-04
4/30/12	11:43 AM	0.05	3.00	330.75	3.97	3.18E-02	2.24E-04
4/30/12	11:46 AM	0.10	6.00	330.66	3.88	3.10E-02	2.24E-04
4/30/12	11:49 AM	0.15	9.00	330.59	3.81	3.05E-02	2.24E-04
4/30/12	11:52 AM	0.20	12.00	330.55	3.77	3.02E-02	4.80E-03
4/30/12	11:55 AM	0.25	15.00	330.52	3.74	2.99E-02	3.20E-03
4/30/12	11:58 AM	0.30	18.00	330.50	3.72	2.98E-02	4.80E-03
4/30/12	12:01 PM	0.35	21.00	330.47	3.69	2.95E-02	3.20E-03
4/30/12	12:04 PM	0.40	24.00	330.45	3.67	2.94E-02	1.60E-03
4/30/12	12:07 PM	0.45	27.00	330.44	3.66	2.93E-02	3.20E-03
4/30/12	12:10 PM	0.50	30.00	330.42	3.64	2.91E-02	1.44E-03
4/30/12	12:20 PM	0.67	40.00	330.39	3.61	2.89E-02	2.40E-03
4/30/12	12:30 PM	0.83	50.00	330.34	3.56	2.85E-02	2.40E-03
4/30/12	12:40 PM	1.00	60.00	330.29	3.51	2.81E-02	1.44E-03
4/30/12	12:50 PM	1.17	70.00	330.26	3.48	2.78E-02	4.80E-04
4/30/12	1:00 PM	1.33	80.00	330.25	3.47	2.78E-02	1.44E-03
4/30/12	1:10 PM	1.50	90.00	330.22	3.44	2.75E-02	1.28E-03
4/30/12	1:25 PM	1.75	105.00	330.18	3.40	2.72E-02	7.20E-04
4/30/12	1:45 PM	2.08	125.00	330.15	3.37	2.70E-02	7.38E-04
4/30/12	1:58 PM	2.30	138.00	330.13	3.35	2.68E-02	8.00E-04
4/30/12	2:10 PM	2.50	150.00	330.11	3.33	2.66E-02	6.40E-04
4/30/12	2:40 PM	3.00	180.00	330.07	3.29	2.63E-02	8.00E-04
4/30/12	3:10 PM	3.50	210.00	330.02	3.24	2.59E-02	3.20E-04
4/30/12	3:40 PM	4.00	240.00	330.00	3.22	2.58E-02	6.40E-04
4/30/12	4:10 PM	4.50	270.00	329.96	3.18	2.54E-02	6.32E-04
4/30/12	5:26 PM	5.77	346.00	329.86	3.08	2.46E-02	4.14E-04
4/30/12	6:24 PM	6.73	404.00	329.81	3.03	2.42E-02	1.73E-04
4/30/12	7:45 PM	8.12	487.00	329.78	3.00	2.40E-02	3.62E-04
4/30/12	8:40 PM	9.00	540.00	329.74	2.96	2.37E-02	4.25E-04
4/30/12	9:59 PM	10.32	619.00	329.67	2.89	2.31E-02	0.00E+00
4/30/12	10:40 PM	11.00	660.00	329.67	2.89	2.31E-02	2.29E-04
4/30/12	12:04 AM	12.40	744.00	329.63	2.85	2.28E-02	1.36E-04
4/30/12	4:01 AM	16.52	991.00	329.56	2.78	2.22E-02	4.65E-04
4/30/12	4:42 AM	17.03	1022.00	329.53	2.75	2.20E-02	1.41E-04
4/30/12	5:58 AM	18.17	1090.00	329.51	2.73	2.18E-02	1.58E-04
4/30/12	8:21 AM	20.70	1242.00	329.46	2.68	2.14E-02	1.64E-04
4/30/12	10:20 AM	22.65	1359.00	329.42	2.64	2.11E-02	1.15E-04
4/30/12	12:24 PM	24.73	1484.00	329.39	2.61	2.09E-02	1.19E-04
4/30/12	9:26 PM	28.77	1726.00	329.33	2.55	2.04E-02	5.05E-05
4/30/12	6:00 PM	30.35	1821.00	329.32	2.54	2.03E-02	8.57E-05
4/30/12	7:53 PM	32.22	1933.00	329.30	2.52	2.02E-02	8.62E-05
4/30/12	10:40 PM	35.00	2100.00	329.27	2.49	1.99E-02	7.15E-05
5/1/12	5:21 AM	41.72	2503.00	329.21	2.43	1.94E-02	2.70E-05
5/1/12	8:20 AM	44.68	2681.00	329.20	2.42	1.94E-02	3.08E-05
5/1/12	1:32 PM	49.88	2993.00	329.18	2.40	1.92E-02	2.73E-05
5/1/12	5:18 PM	55.75	3345.00	329.16	2.38	1.90E-02	1.11E-04
5/2/12	1:12 AM	61.53	3692.00	329.08	2.30	1.84E-02	2.22E-05
5/2/12	8:25 AM	68.75	4125.00	329.06	2.28	1.82E-02	2.72E-05
5/2/12	2:01 PM	74.37	4462.00	328.99	2.21	1.77E-02	2.72E-05
5/2/12	11:01 PM	83.35	5001.00	328.99	2.21	1.77E-02	2.72E-05
5/3/12	10:46 AM	96.12	5767.00	328.93	2.15	1.72E-02	2.72E-05
5/4/12	2:21 AM	110.70	6642.00	328.89	2.11	1.69E-02	2.72E-05
5/4/12	2:30 PM	122.80	7368.00	328.86	2.08	1.66E-02	2.72E-05
5/7/12	3:45 PM	196.12	11767.00	328.66	1.88	1.50E-02	2.72E-05

APPENDIX E: DRYING INDEX TESTING DATA

Drying Index A1.3							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	11:40 AM	0.00	0.00	323.12	4.32	3.46E-02	2.53E-04
4/30/12	11:43 AM	0.05	3.00	323.00	4.20	3.36E-02	2.53E-04
4/30/12	11:46 AM	0.10	6.00	322.92	4.12	3.30E-02	2.53E-04
4/30/12	11:49 AM	0.15	9.00	322.83	4.03	3.22E-02	2.53E-04
4/30/12	11:52 AM	0.20	12.00	322.80	4.00	3.20E-02	6.40E-03
4/30/12	11:55 AM	0.25	15.00	322.76	3.96	3.17E-02	3.20E-03
4/30/12	11:58 AM	0.30	18.00	322.74	3.94	3.15E-02	3.20E-03
4/30/12	12:01 PM	0.35	21.00	322.72	3.92	3.14E-02	3.20E-03
4/30/12	12:04 PM	0.40	24.00	322.70	3.90	3.12E-02	1.60E-03
4/30/12	12:07 PM	0.45	27.00	322.69	3.89	3.11E-02	3.20E-03
4/30/12	12:10 PM	0.50	30.00	322.67	3.87	3.10E-02	1.44E-03
4/30/12	12:20 PM	0.67	40.00	322.64	3.84	3.07E-02	3.36E-03
4/30/12	12:30 PM	0.83	50.00	322.57	3.77	3.02E-02	9.60E-04
4/30/12	12:40 PM	1.00	60.00	322.55	3.75	3.00E-02	1.44E-03
4/30/12	12:50 PM	1.17	70.00	322.52	3.72	2.98E-02	4.80E-04
4/30/12	1:00 PM	1.33	80.00	322.51	3.71	2.97E-02	1.44E-03
4/30/12	1:10 PM	1.50	90.00	322.48	3.68	2.94E-02	1.60E-03
4/30/12	1:25 PM	1.75	105.00	322.43	3.63	2.90E-02	9.60E-04
4/30/12	1:45 PM	2.08	125.00	322.39	3.59	2.87E-02	7.38E-04
4/30/12	1:58 PM	2.30	138.00	322.37	3.57	2.86E-02	0.00E+00
4/30/12	2:10 PM	2.50	150.00	322.37	3.57	2.86E-02	9.60E-04
4/30/12	2:40 PM	3.00	180.00	322.31	3.51	2.81E-02	6.40E-04
4/30/12	3:10 PM	3.50	210.00	322.27	3.47	2.78E-02	4.80E-04
4/30/12	3:40 PM	4.00	240.00	322.24	3.44	2.75E-02	6.40E-04
4/30/12	4:10 PM	4.50	270.00	322.20	3.40	2.72E-02	6.95E-04
4/30/12	5:26 PM	5.77	346.00	322.09	3.29	2.63E-02	4.97E-04
4/30/12	6:24 PM	6.73	404.00	322.03	3.23	2.58E-02	1.73E-04
4/30/12	7:45 PM	8.12	487.00	322.00	3.20	2.56E-02	4.53E-04
4/30/12	8:40 PM	9.00	540.00	321.95	3.15	2.52E-02	3.65E-04
4/30/12	9:59 PM	10.32	619.00	321.89	3.09	2.47E-02	2.34E-04
4/30/12	10:40 PM	11.00	660.00	321.87	3.07	2.46E-02	1.71E-04
4/30/12	12:04 AM	12.40	744.00	321.84	3.04	2.43E-02	1.75E-04
4/30/12	4:01 AM	16.52	991.00	321.75	2.95	2.36E-02	4.65E-04
4/30/12	4:42 AM	17.03	1022.00	321.72	2.92	2.34E-02	1.41E-04
4/30/12	5:58 AM	18.17	1090.00	321.70	2.90	2.32E-02	1.89E-04
4/30/12	8:21 AM	20.70	1242.00	321.64	2.84	2.27E-02	1.23E-04
4/30/12	10:20 AM	22.65	1359.00	321.61	2.81	2.25E-02	1.15E-04
4/30/12	12:24 PM	24.73	1484.00	321.58	2.78	2.22E-02	1.19E-04
4/30/12	4:26 PM	28.77	1726.00	321.52	2.72	2.18E-02	5.05E-05
4/30/12	6:00 PM	30.35	1821.00	321.51	2.71	2.17E-02	1.71E-04
4/30/12	7:53 PM	32.22	1933.00	321.47	2.67	2.14E-02	5.75E-05
4/30/12	10:40 PM	35.00	2100.00	321.45	2.65	2.12E-02	9.53E-05
5/1/12	5:21 AM	41.72	2503.00	321.37	2.57	2.06E-02	2.70E-05
5/1/12	8:20 AM	44.68	2681.00	321.36	2.56	2.05E-02	3.08E-05
5/1/12	1:32 PM	49.88	2993.00	321.34	2.54	2.03E-02	2.73E-05
5/1/12	5:18 PM	55.75	2993.00	321.32	2.52	2.02E-02	1.11E-04
5/2/12	1:12 AM	61.53	3692.00	321.24	2.44	1.95E-02	5.54E-05
5/2/12	8:25 AM	68.75	4125.00	321.19	2.39	1.91E-02	2.67E-05
5/2/12	2:01 PM	74.37	4462.00	321.14	2.34	1.87E-02	2.67E-05
5/2/12	11:01 PM	83.35	5001.00	321.12	2.32	1.86E-02	2.67E-05
5/3/12	10:46 AM	96.12	5767.00	321.06	2.26	1.81E-02	2.67E-05
5/4/12	2:21 AM	110.70	6642.00	321.00	2.20	1.76E-02	2.67E-05
5/4/12	2:30 PM	122.80	7368.00	320.98	2.18	1.74E-02	2.67E-05
5/7/12	3:45 PM	196.12	11767.00	320.75	1.95	1.56E-02	2.67E-05

APPENDIX E: DRYING INDEX TESTING DATA



APPENDIX E: DRYING INDEX TESTING DATA

Drying Curve B1.1							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	10:23 AM	0.00	0.00	322.13	4.97	3.98E-02	1.81E-02
4/30/12	10:26 AM	0.05	3.00	322.00	4.84	3.87E-02	1.81E-02
4/30/12	10:29 AM	0.10	6.00	321.89	4.73	3.78E-02	1.81E-02
4/30/12	10:32 AM	0.15	9.00	321.78	4.62	3.70E-02	1.81E-02
4/30/12	10:35 AM	0.20	12.00	321.70	4.54	3.63E-02	1.81E-02
4/30/12	10:38 AM	0.25	15.00	321.54	4.38	3.50E-02	1.81E-02
4/30/12	10:43 AM	0.33	20.00	321.46	4.30	3.44E-02	1.82E-02
4/30/12	10:48 AM	0.42	25.00	321.27	4.11	3.29E-02	8.64E-03
4/30/12	10:53 AM	0.50	30.00	321.18	4.02	3.22E-02	1.34E-02
4/30/12	11:03 AM	0.67	40.00	320.90	3.74	2.99E-02	3.36E-03
4/30/12	11:13 AM	0.83	50.00	320.83	3.67	2.94E-02	3.36E-03
4/30/12	11:23 AM	1.00	60.00	320.76	3.60	2.88E-02	1.92E-03
4/30/12	11:33 AM	1.17	70.00	320.72	3.56	2.85E-02	1.92E-03
4/30/12	11:43 AM	1.33	80.00	320.68	3.52	2.82E-02	1.44E-03
4/30/12	11:53 AM	1.50	90.00	320.65	3.49	2.79E-02	1.28E-03
4/30/12	12:08 PM	1.75	105.00	320.61	3.45	2.76E-02	1.28E-03
4/30/12	12:23 PM	2.00	120.00	320.57	3.41	2.73E-02	9.60E-04
4/30/12	12:38 PM	2.25	135.00	320.54	3.38	2.70E-02	1.60E-03
4/30/12	12:53 PM	2.50	150.00	320.49	3.33	2.66E-02	6.40E-04
4/30/12	1:23 PM	3.00	210.00	320.45	3.29	2.63E-02	6.40E-04
4/30/12	1:53 PM	3.50	270.00	320.41	3.25	2.60E-02	1.28E-03
4/30/12	2:23 PM	4.00	330.00	320.33	3.17	2.54E-02	8.00E-04
4/30/12	3:53 PM	4.50	270.00	320.28	3.12	2.50E-02	5.60E-04
4/30/12	4:53 PM	5.50	331.00	320.21	3.05	2.44E-02	4.00E-04
4/30/12	5:53 PM	6.50	390.00	320.16	3.00	2.40E-02	1.60E-04
4/30/12	6:53 PM	8.50	510.00	320.12	2.96	2.37E-02	2.40E-04
4/30/12	7:53 PM	9.50	570.00	320.09	2.93	2.34E-02	7.27E-04
4/30/12	8:59 PM	10.60	636.00	319.99	2.83	2.26E-02	1.71E-04
5/1/12	6:24 AM	19.02	1141.00	319.81	2.65	2.12E-02	2.45E-04
5/1/12	8:20 AM	21.95	1317.00	319.72	2.56	2.05E-02	4.63E-05
5/1/12	1:31 PM	27.13	1628.00	319.69	2.53	2.02E-02	2.07E-04
5/1/12	5:18 PM	29.83	1790.00	319.62	2.46	1.97E-02	1.41E-04
5/2/12	1:12 AM	37.75	2265.00	319.48	2.32	1.86E-02	1.11E-04
5/2/12	8:25 AM	44.97	2698.00	319.38	2.22	1.78E-02	1.14E-04
5/2/12	2:01 PM	50.57	3034.00	319.30	2.14	1.71E-02	3.88E-05
5/2/12	11:01 PM	59.57	3574.00	319.27	2.11	1.69E-02	3.88E-05
5/3/12	10:46 AM	72.40	4344.00	319.16	2.00	1.60E-02	3.88E-05
5/4/12	2:21 AM	86.90	5214.00	319.08	1.92	1.54E-02	3.88E-05
5/4/12	2:30 PM	99.03	5942.00	319.03	1.87	1.50E-02	3.88E-05
5/7/12	3:45 PM	172.33	10340.00	318.70	1.54	1.23E-02	3.88E-05
5/8/12	10:35 AM	191.12	11467.00	318.61	1.45	1.16E-02	3.88E-05

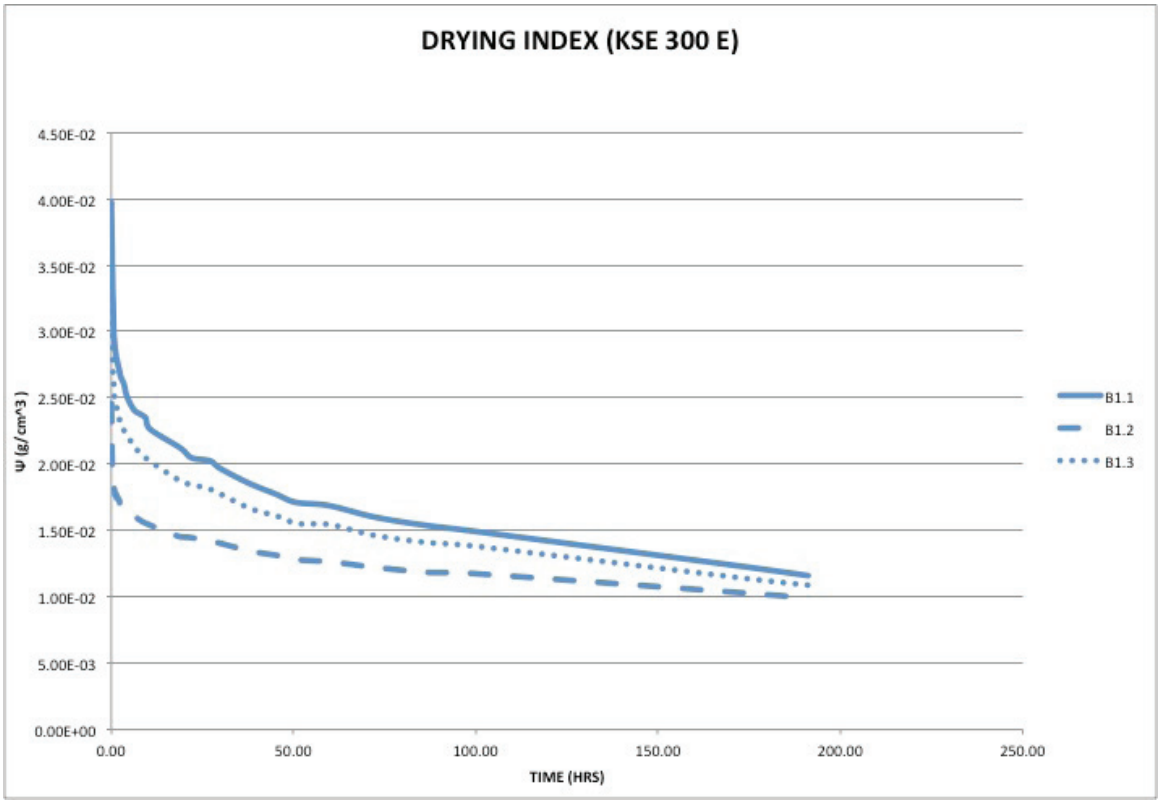
APPENDIX E: DRYING INDEX TESTING DATA

Drying Index B1.2							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	10:55 AM	0.00	0.00	323.90	3.07	2.46E-02	1.89E-02
4/30/12	10:58 AM	0.05	3.00	323.80	2.97	2.38E-02	1.89E-02
4/30/12	11:01 AM	0.10	6.00	323.69	2.86	2.29E-02	1.89E-02
4/30/12	11:04 AM	0.15	9.00	323.50	2.67	2.14E-02	1.89E-02
4/30/12	11:07 AM	0.20	12.00	323.42	2.59	2.07E-02	1.89E-02
4/30/12	11:10 AM	0.25	15.00	323.34	2.51	2.01E-02	1.06E-02
4/30/12	11:15 AM	0.33	20.00	323.23	2.40	1.92E-02	2.88E-03
4/30/12	11:20 AM	0.42	25.00	323.20	2.37	1.90E-02	2.88E-03
4/30/12	11:25 AM	0.50	30.00	323.17	2.34	1.87E-02	1.92E-03
4/30/12	11:35 AM	0.67	40.00	323.13	2.30	1.84E-02	1.92E-03
4/30/12	11:45 AM	0.83	50.00	323.09	2.26	1.81E-02	9.60E-04
4/30/12	11:55 AM	1.00	60.00	323.07	2.24	1.79E-02	9.60E-04
4/30/12	12:05 PM	1.17	70.00	323.05	2.22	1.78E-02	4.80E-04
4/30/12	12:15 PM	1.33	80.00	323.04	2.21	1.77E-02	9.60E-04
4/30/12	12:25 PM	1.50	90.00	323.02	2.19	1.75E-02	3.20E-04
4/30/12	12:40 PM	1.75	105.00	323.01	2.18	1.74E-02	3.20E-04
4/30/12	12:55 PM	2.00	120.00	323.00	2.17	1.74E-02	6.40E-04
4/30/12	1:10 PM	2.25	135.00	322.98	2.15	1.72E-02	6.40E-04
4/30/12	1:25 PM	2.50	150.00	322.96	2.13	1.70E-02	3.20E-04
4/30/12	1:55 PM	3.00	180.00	322.94	2.11	1.69E-02	1.60E-04
4/30/12	2:25 PM	3.50	210.00	322.93	2.10	1.68E-02	3.20E-04
4/30/12	3:25 PM	4.50	270.00	322.89	2.06	1.65E-02	2.40E-04
4/30/12	4:25 PM	5.50	330.00	322.86	2.03	1.62E-02	1.60E-04
4/30/12	5:25 PM	6.50	390.00	322.84	2.01	1.61E-02	2.40E-04
4/30/12	6:25 PM	7.50	450.00	322.81	1.98	1.58E-02	1.60E-04
4/30/12	7:55 PM	9.00	540.00	322.78	1.95	1.56E-02	1.17E-04
4/30/12	8:59 PM	11.73	704.00	322.74	1.91	1.53E-02	1.07E-04
5/1/12	6:24 AM	18.47	1108.00	322.65	1.82	1.46E-02	2.71E-05
5/1/12	8:20 AM	21.42	1285.00	322.64	1.81	1.45E-02	4.62E-05
5/1/12	1:31 PM	26.62	1597.00	322.61	1.78	1.42E-02	6.40E-05
5/1/12	5:18 PM	30.37	1822.00	322.58	1.75	1.40E-02	7.09E-05
5/2/12	1:12 AM	38.27	2296.00	322.51	1.68	1.34E-02	4.42E-05
5/2/12	8:25 AM	45.50	2730.00	322.47	1.64	1.31E-02	2.08E-05
5/2/12	2:01 PM	51.13	3068.00	322.43	1.60	1.28E-02	2.08E-05
5/2/12	11:01 PM	60.07	3604.00	322.41	1.58	1.26E-02	2.08E-05
5/3/12	10:46 AM	71.87	4312.00	322.36	1.53	1.22E-02	2.08E-05
5/4/12	2:21 AM	86.90	5214.00	322.31	1.48	1.18E-02	2.08E-05
5/4/12	2:30 PM	99.03	5942.00	322.30	1.47	1.18E-02	2.08E-05
5/7/12	3:45 PM	172.33	10340.00	322.12	1.29	1.03E-02	2.08E-05
5/8/12	10:35 AM	191.12	11467.00	322.07	1.24	9.92E-03	2.08E-05

APPENDIX E: DRYING INDEX TESTING DATA

Drying Index B1.3							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	10:55 AM	0.00	0.00	327.88	4.40	3.52E-02	2.17E-02
4/30/12	10:58 AM	0.05	3.00	327.77	4.29	3.43E-02	2.17E-02
4/30/12	11:01 AM	0.10	6.00	327.65	4.17	3.34E-02	2.17E-02
4/30/12	11:04 AM	0.15	9.00	327.43	3.95	3.16E-02	2.17E-02
4/30/12	11:07 AM	0.20	12.00	327.33	3.85	3.08E-02	2.17E-02
4/30/12	11:10 AM	0.25	15.00	327.24	3.76	3.01E-02	2.17E-02
4/30/12	11:15 AM	0.33	20.00	327.06	3.58	2.86E-02	1.25E-02
4/30/12	11:20 AM	0.42	25.00	326.93	3.45	2.76E-02	9.60E-03
4/30/12	11:25 AM	0.50	30.00	326.83	3.35	2.68E-02	4.32E-03
4/30/12	11:35 AM	0.67	40.00	326.74	3.26	2.61E-02	6.24E-03
4/30/12	11:45 AM	0.83	50.00	326.61	3.13	2.50E-02	9.60E-04
4/30/12	11:55 AM	1.00	60.00	326.59	3.11	2.49E-02	1.44E-03
4/30/12	12:05 PM	1.17	70.00	326.56	3.08	2.46E-02	1.92E-03
4/30/12	12:15 PM	1.33	80.00	326.52	3.04	2.43E-02	0.00E+00
4/30/12	12:25 PM	1.50	90.00	326.52	3.04	2.43E-02	1.92E-03
4/30/12	12:40 PM	1.75	105.00	326.46	2.98	2.38E-02	9.60E-04
4/30/12	12:55 PM	2.00	120.00	326.43	2.95	2.36E-02	9.60E-04
4/30/12	1:10 PM	2.25	135.00	326.40	2.92	2.34E-02	9.60E-04
4/30/12	1:25 PM	2.50	150.00	326.37	2.89	2.31E-02	8.00E-04
4/30/12	1:55 PM	3.00	180.00	326.32	2.84	2.27E-02	4.80E-04
4/30/12	2:25 PM	3.50	210.00	326.29	2.81	2.25E-02	4.00E-04
4/30/12	3:25 PM	4.50	270.00	326.24	2.76	2.21E-02	4.00E-04
4/30/12	4:25 PM	5.50	330.00	326.19	2.71	2.17E-02	2.40E-04
4/30/12	5:25 PM	6.50	390.00	326.16	2.68	2.14E-02	5.60E-04
4/30/12	6:25 PM	7.50	450.00	326.09	2.61	2.09E-02	2.13E-04
4/30/12	7:55 PM	9.00	540.00	326.05	2.57	2.06E-02	2.05E-04
4/30/12	8:59 PM	11.73	704.00	325.98	2.50	2.00E-02	1.78E-04
5/1/12	6:24 AM	18.47	1108.00	325.83	2.35	1.88E-02	1.08E-04
5/1/12	8:20 AM	21.42	1285.00	325.79	2.31	1.85E-02	6.15E-05
5/1/12	1:31 PM	26.62	1597.00	325.75	2.27	1.82E-02	1.28E-04
5/1/12	5:18 PM	30.37	1822.00	325.69	2.21	1.77E-02	1.32E-04
5/2/12	1:12 AM	38.27	2296.00	325.56	2.08	1.66E-02	7.74E-05
5/2/12	8:25 AM	45.50	2730.00	325.49	2.01	1.61E-02	3.43E-05
5/2/12	2:01 PM	51.13	3068.00	325.42	1.94	1.55E-02	3.43E-05
5/2/12	11:01 PM	60.07	3604.00	325.41	1.93	1.54E-02	3.43E-05
5/3/12	10:46 AM	71.87	4312.00	325.31	1.83	1.46E-02	3.43E-05
5/4/12	2:21 AM	86.90	5214.00	325.24	1.76	1.41E-02	3.43E-05
5/4/12	2:30 PM	99.03	5942.00	325.21	1.73	1.38E-02	3.43E-05
5/7/12	3:45 PM	172.33	10340.00	324.91	1.43	1.14E-02	3.43E-05
5/8/12	10:35 AM	191.12	11467.00	324.84	1.36	1.09E-02	3.43E-05

APPENDIX E: DRYING INDEX TESTING DATA



APPENDIX E: DRYING INDEX TESTING DATA

Drying Index C1.1							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	12:00 PM	0.00	0.00	328.27	3.30	2.64E-02	1.77E-02
4/30/12	12:03 PM	0.05	3.00	328.14	3.17	2.54E-02	1.77E-02
4/30/12	12:06 PM	0.10	6.00	328.01	3.04	2.43E-02	1.77E-02
4/30/12	12:09 PM	0.15	9.00	327.91	2.94	2.35E-02	1.77E-02
4/30/12	12:12 PM	0.20	12.00	327.76	2.79	2.23E-02	1.77E-02
4/30/12	12:15 PM	0.25	15.00	327.69	2.72	2.18E-02	1.77E-02
4/30/12	12:20 PM	0.33	20.00	327.54	2.57	2.06E-02	1.77E-02
4/30/12	12:25 PM	0.42	25.00	327.47	2.50	2.00E-02	1.44E-02
4/30/12	12:30 PM	0.50	30.00	327.32	2.35	1.88E-02	7.68E-03
4/30/12	12:40 PM	0.67	40.00	327.16	2.19	1.75E-02	4.32E-03
4/30/12	12:50 PM	0.83	50.00	327.07	2.10	1.68E-02	4.80E-04
4/30/12	1:00 PM	1.00	60.00	327.06	2.09	1.67E-02	4.80E-04
4/30/12	1:10 PM	1.17	70.00	327.05	2.08	1.66E-02	1.44E-03
4/30/12	1:20 PM	1.33	80.00	327.02	2.05	1.64E-02	9.60E-04
4/30/12	1:30 PM	1.50	90.00	327.00	2.03	1.62E-02	6.40E-04
4/30/12	1:45 PM	1.75	105.00	326.98	2.01	1.61E-02	3.20E-04
4/30/12	2:00 PM	2.00	120.00	326.97	2.00	1.60E-02	2.40E-04
4/30/12	2:20 PM	2.33	140.00	326.96	1.99	1.59E-02	4.80E-04
4/30/12	2:30 PM	2.50	150.00	326.95	1.98	1.58E-02	3.20E-04
4/30/12	3:00 PM	3.00	180.00	326.93	1.96	1.57E-02	4.80E-04
4/30/12	3:30 PM	3.50	210.00	326.90	1.93	1.54E-02	1.60E-04
4/30/12	4:30 PM	4.50	270.00	326.88	1.91	1.53E-02	2.40E-04
4/30/12	5:30 PM	5.50	330.00	326.85	1.88	1.50E-02	3.20E-04
4/30/12	6:30 PM	6.50	390.00	326.81	1.84	1.47E-02	5.33E-05
4/30/12	8:00 PM	8.00	480.00	326.80	1.83	1.46E-02	1.22E-04
4/30/12	10:37 PM	10.62	637.00	326.76	1.79	1.43E-02	1.06E-04
5/1/12	5:25 AM	17.42	1045.00	326.67	1.70	1.36E-02	5.55E-05
5/1/12	8:18 AM	20.30	1218.00	326.65	1.68	1.34E-02	1.51E-05
5/1/12	1:25 PM	25.58	1535.00	326.64	1.67	1.34E-02	9.41E-05
5/1/12	5:18 PM	29.83	1790.00	326.59	1.62	1.30E-02	7.07E-05
5/2/12	1:12 AM	37.75	2265.00	326.52	1.55	1.24E-02	5.54E-05
5/2/12	8:25 AM	44.97	2698.00	326.47	1.50	1.20E-02	2.08E-05
5/2/12	2:01 PM	50.57	3034.00	326.44	1.47	1.18E-02	2.08E-05
5/2/12	11:01 PM	59.57	3574.00	326.43	1.46	1.17E-02	2.08E-05
5/3/12	10:45 AM	70.77	4246.00	326.37	1.40	1.12E-02	2.08E-05
5/4/12	2:21 AM	86.37	5182.00	326.33	1.36	1.09E-02	2.08E-05
5/4/12	2:30 PM	98.50	5910.00	326.31	1.34	1.07E-02	2.08E-05
5/7/12	3:45 PM	171.80	10308.00	326.13	1.16	9.28E-03	2.08E-05
5/8/12	10:35 AM	190.58	11435.00	326.08	1.11	8.88E-03	2.08E-05

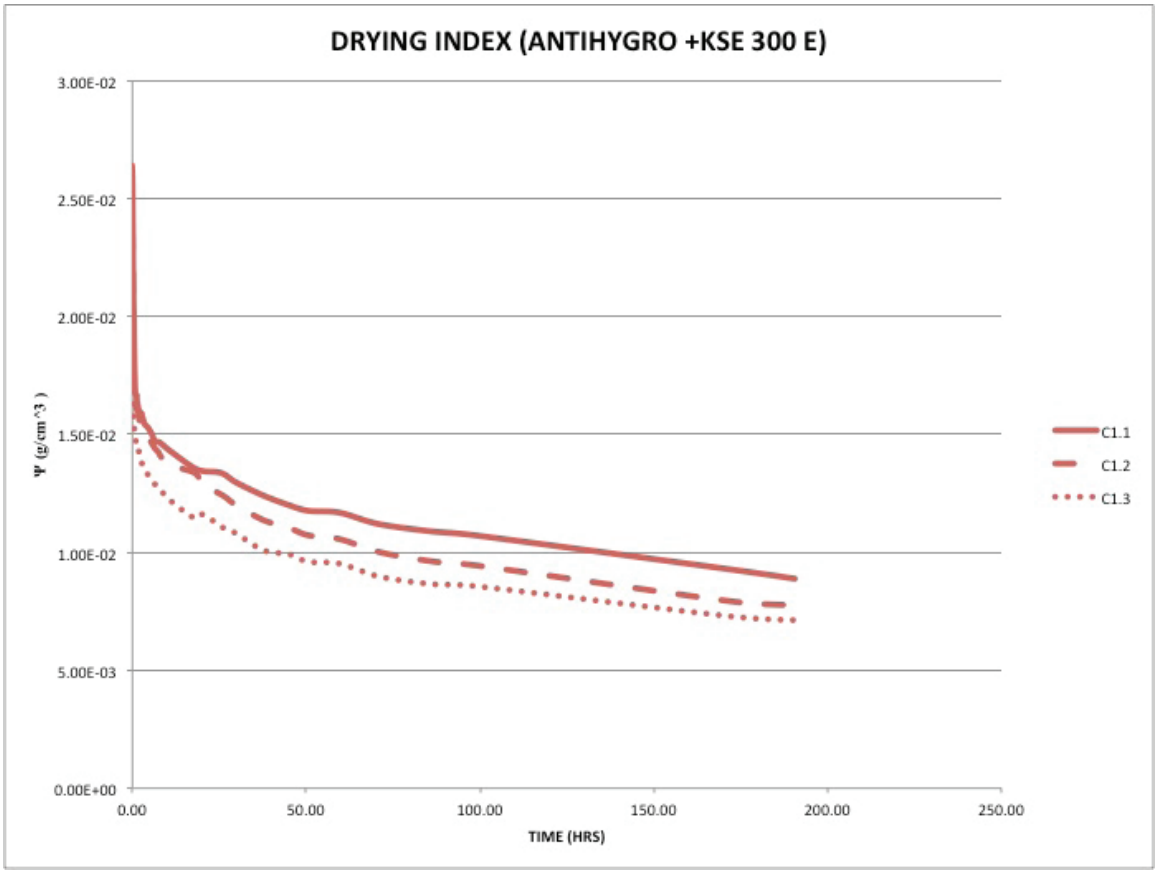
APPENDIX E: DRYING INDEX TESTING DATA

Drying Index C1.2							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	11:27 AM	0.00	0.00	323.58	2.96	2.37E-02	2.14E-02
4/30/12	11:30 AM	0.05	3.00	323.44	2.82	2.26E-02	2.14E-02
4/30/12	11:33 AM	0.10	6.00	323.33	2.71	2.17E-02	2.14E-02
4/30/12	11:36 AM	0.15	9.00	323.17	2.55	2.04E-02	2.14E-02
4/30/12	11:39 AM	0.20	12.00	323.11	2.49	1.99E-02	1.28E-02
4/30/12	11:42 AM	0.25	15.00	323.03	2.41	1.93E-02	1.25E-02
4/30/12	11:47 AM	0.33	20.00	322.90	2.28	1.82E-02	7.68E-03
4/30/12	11:52 AM	0.42	25.00	322.82	2.20	1.76E-02	5.76E-03
4/30/12	11:57 AM	0.50	30.00	322.76	2.14	1.71E-02	2.40E-03
4/30/12	12:07 PM	0.67	40.00	322.71	2.09	1.67E-02	9.60E-04
4/30/12	12:17 PM	0.83	50.00	322.69	2.07	1.66E-02	1.44E-03
4/30/12	12:27 PM	1.00	60.00	322.66	2.04	1.63E-02	9.60E-04
4/30/12	12:37 PM	1.17	70.00	322.64	2.02	1.62E-02	9.60E-04
4/30/12	12:47 PM	1.33	80.00	322.62	2.00	1.60E-02	0.00E+00
4/30/12	12:57 PM	1.50	90.00	322.62	2.00	1.60E-02	3.20E-04
4/30/12	1:12 PM	1.75	105.00	322.61	1.99	1.59E-02	1.28E-03
4/30/12	1:27 PM	2.00	120.00	322.57	1.95	1.56E-02	0.00E+00
4/30/12	1:42 PM	2.25	135.00	322.57	1.95	1.56E-02	9.60E-04
4/30/12	2:07 PM	2.50	150.00	322.54	1.92	1.54E-02	1.37E-04
4/30/12	2:32 PM	3.08	185.00	322.53	1.91	1.53E-02	3.84E-04
4/30/12	2:57 PM	3.50	210.00	322.51	1.89	1.51E-02	2.40E-04
4/30/12	3:57 PM	4.50	270.00	322.48	1.86	1.49E-02	2.40E-04
4/30/12	4:57 PM	5.50	330.00	322.45	1.83	1.46E-02	2.40E-04
4/30/12	5:57 PM	6.50	390.00	322.42	1.80	1.44E-02	1.60E-04
4/30/12	6:57 PM	7.50	450.00	322.40	1.78	1.42E-02	2.40E-04
4/30/12	7:57 PM	8.50	510.00	322.37	1.75	1.40E-02	1.20E-04
4/30/12	8:59 PM	11.17	670.00	322.33	1.71	1.37E-02	4.71E-05
5/1/12	6:24 AM	17.97	1078.00	322.29	1.67	1.34E-02	2.06E-04
5/1/12	8:20 AM	20.30	1218.00	322.23	1.61	1.29E-02	8.28E-05
5/1/12	1:31 PM	26.10	1566.00	322.17	1.55	1.24E-02	1.07E-04
5/1/12	5:18 PM	29.83	1790.00	322.12	1.50	1.20E-02	8.08E-05
5/2/12	1:12 AM	37.75	2265.00	322.04	1.42	1.14E-02	4.43E-05
5/2/12	8:25 AM	44.97	2698.00	322.00	1.38	1.10E-02	5.71E-05
5/2/12	2:01 PM	50.57	3034.00	321.96	1.34	1.07E-02	1.78E-05
5/2/12	11:01 PM	59.57	3574.00	321.94	1.32	1.06E-02	4.77E-05
5/3/12	10:45 AM	71.30	4278.00	321.87	1.25	1.00E-02	1.91E-05
5/4/12	2:21 AM	86.90	5214.00	321.82	1.20	9.60E-03	1.91E-05
5/4/12	2:30 PM	99.03	5942.00	321.80	1.18	9.44E-03	1.91E-05
5/7/12	3:45 PM	172.33	10340.00	321.61	0.99	7.92E-03	1.91E-05
5/8/12	10:35 AM	191.12	11467.00	321.59	0.97	7.76E-03	1.91E-05

APPENDIX E: DRYING INDEX TESTING DATA

Drying Index C1.3							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
4/30/12	11:27 AM	0.00	0.00	323.31	2.69	2.15E-02	1.90E-02
4/30/12	11:30 AM	0.05	3.00	323.17	2.55	2.04E-02	1.90E-02
4/30/12	11:33 AM	0.10	6.00	323.07	2.45	1.96E-02	1.90E-02
4/30/12	11:36 AM	0.15	9.00	322.92	2.30	1.84E-02	1.90E-02
4/30/12	11:39 AM	0.20	12.00	322.84	2.22	1.78E-02	1.90E-02
4/30/12	11:42 AM	0.25	15.00	322.77	2.15	1.72E-02	1.25E-02
4/30/12	11:47 AM	0.33	20.00	322.64	2.02	1.62E-02	4.80E-03
4/30/12	11:52 AM	0.42	25.00	322.59	1.97	1.58E-02	4.80E-03
4/30/12	11:57 AM	0.50	30.00	322.54	1.92	1.54E-02	1.92E-03
4/30/12	12:07 PM	0.67	40.00	322.50	1.88	1.50E-02	4.80E-04
4/30/12	12:17 PM	0.83	50.00	322.49	1.87	1.50E-02	1.44E-03
4/30/12	12:27 PM	1.00	60.00	322.46	1.84	1.47E-02	4.80E-04
4/30/12	12:37 PM	1.17	70.00	322.45	1.83	1.46E-02	9.60E-04
4/30/12	12:47 PM	1.33	80.00	322.43	1.81	1.45E-02	4.80E-04
4/30/12	12:57 PM	1.50	90.00	322.42	1.80	1.44E-02	0.00E+00
4/30/12	1:12 PM	1.75	105.00	322.42	1.80	1.44E-02	1.28E-03
4/30/12	1:27 PM	2.00	120.00	322.38	1.76	1.41E-02	3.20E-04
4/30/12	1:42 PM	2.25	135.00	322.37	1.75	1.40E-02	6.40E-04
4/30/12	2:07 PM	2.50	150.00	322.35	1.73	1.38E-02	2.74E-04
4/30/12	2:32 PM	3.08	185.00	322.33	1.71	1.37E-02	3.84E-04
4/30/12	2:57 PM	3.50	210.00	322.31	1.69	1.35E-02	2.40E-04
4/30/12	3:57 PM	4.50	270.00	322.28	1.66	1.33E-02	2.40E-04
4/30/12	4:57 PM	5.50	330.00	322.25	1.63	1.30E-02	1.60E-04
4/30/12	5:57 PM	6.50	390.00	322.23	1.61	1.29E-02	2.40E-04
4/30/12	6:57 PM	7.50	450.00	322.20	1.58	1.26E-02	8.00E-05
4/30/12	7:57 PM	8.50	510.00	322.19	1.57	1.26E-02	1.50E-04
4/30/12	8:59 PM	11.17	670.00	322.14	1.52	1.22E-02	1.06E-04
5/1/12	6:24 AM	17.97	1078.00	322.05	1.43	1.14E-02	-6.86E-05
5/1/12	8:20 AM	20.30	1218.00	322.07	1.45	1.16E-02	9.66E-05
5/1/12	1:31 PM	26.10	1566.00	322.00	1.38	1.10E-02	6.43E-05
5/1/12	5:18 PM	29.83	1790.00	321.97	1.35	1.08E-02	9.09E-05
5/2/12	1:12 AM	37.75	2265.00	321.88	1.26	1.01E-02	2.22E-05
5/2/12	8:25 AM	44.97	2698.00	321.86	1.24	9.92E-03	5.71E-05
5/2/12	2:01 PM	50.57	3034.00	321.82	1.20	9.60E-03	8.89E-06
5/2/12	11:01 PM	59.57	3574.00	321.81	1.19	9.52E-03	4.77E-05
5/3/12	10:45 AM	71.30	4278.00	321.74	1.12	8.96E-03	1.57E-05
5/4/12	2:21 AM	86.90	5214.00	321.70	1.08	8.64E-03	1.57E-05
5/4/12	2:30 PM	99.03	5942.00	321.69	1.07	8.56E-03	1.57E-05
5/7/12	3:45 PM	172.33	10340.00	321.53	0.91	7.28E-03	1.57E-05
5/8/12	10:35 AM	191.12	11467.00	321.51	0.89	7.12E-03	1.57E-05

APPENDIX E: DRYING INDEX TESTING DATA



APPENDIX E: DRYING INDEX TESTING DATA

Drying Index D1.1							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
5/1/12	12:40 PM	0.00	0.00	320.74	2.88	2.30E-02	8.24E-03
5/1/12	12:43 PM	0.03	2.00	320.69	2.83	2.26E-02	8.24E-03
5/1/12	12:46 PM	0.10	6.00	320.63	2.77	2.22E-02	8.24E-03
5/1/12	12:49 PM	0.15	9.00	320.57	2.71	2.17E-02	8.24E-03
5/1/12	12:52 PM	0.20	12.00	320.52	2.66	2.13E-02	8.24E-03
5/1/12	12:55 PM	0.25	15.00	320.46	2.60	2.08E-02	8.24E-03
5/1/12	1:00 PM	0.33	20.00	320.39	2.53	2.02E-02	8.24E-03
5/1/12	1:05 PM	0.42	25.00	320.27	2.41	1.93E-02	8.24E-03
5/1/12	1:10 PM	0.50	30.00	320.24	2.38	1.90E-02	8.24E-03
5/1/12	1:20 PM	0.68	41.00	320.18	2.32	1.86E-02	1.20E-03
5/1/12	1:25 PM	0.75	45.00	320.17	2.31	1.85E-02	0.00E+00
5/1/12	1:30 PM	0.83	50.00	320.17	2.31	1.85E-02	9.60E-04
5/1/12	1:35 PM	0.92	55.00	320.16	2.30	1.84E-02	0.00E+00
5/1/12	1:40 PM	1.00	60.00	320.16	2.30	1.84E-02	8.73E-04
5/1/12	1:51 PM	1.18	71.00	320.14	2.28	1.82E-02	0.00E+00
5/1/12	2:00 PM	1.33	80.00	320.14	2.28	1.82E-02	8.00E-04
5/1/12	2:18 PM	1.63	98.00	320.11	2.25	1.80E-02	0.00E+00
5/1/12	2:31 PM	1.85	111.00	320.11	2.25	1.80E-02	4.11E-04
5/1/12	3:06 PM	2.43	146.00	320.08	2.22	1.78E-02	3.43E-04
5/1/12	3:20 PM	2.67	160.00	320.07	2.21	1.77E-02	1.50E-04
5/1/12	3:52 PM	3.20	192.00	320.06	2.20	1.76E-02	2.53E-04
5/1/12	4:12 PM	3.52	211.00	320.05	2.19	1.75E-02	2.87E-04
5/1/12	5:17 PM	4.63	278.00	320.01	2.15	1.72E-02	1.72E-04
5/2/12	1:13 AM	12.55	753.00	319.84	1.98	1.58E-02	1.01E-04
5/2/12	8:23 AM	19.70	1182.00	319.75	1.89	1.51E-02	1.13E-04
5/2/12	2:03 PM	25.38	1523.00	319.67	1.81	1.45E-02	3.58E-05
5/2/12	10:59 PM	34.32	2059.00	319.63	1.77	1.42E-02	6.13E-05
5/3/12	10:46 AM	46.07	2764.00	319.54	1.68	1.34E-02	2.59E-05
5/4/12	2:21 AM	61.70	3702.00	319.47	1.61	1.29E-02	2.59E-05
5/4/12	2:30 PM	73.80	4428.00	319.45	1.59	1.27E-02	2.59E-05
5/7/12	3:45 PM	147.10	8826.00	319.20	1.34	1.07E-02	2.59E-05
5/8/12	10:35 AM	165.92	9955.00	319.15	1.29	1.03E-02	2.59E-05

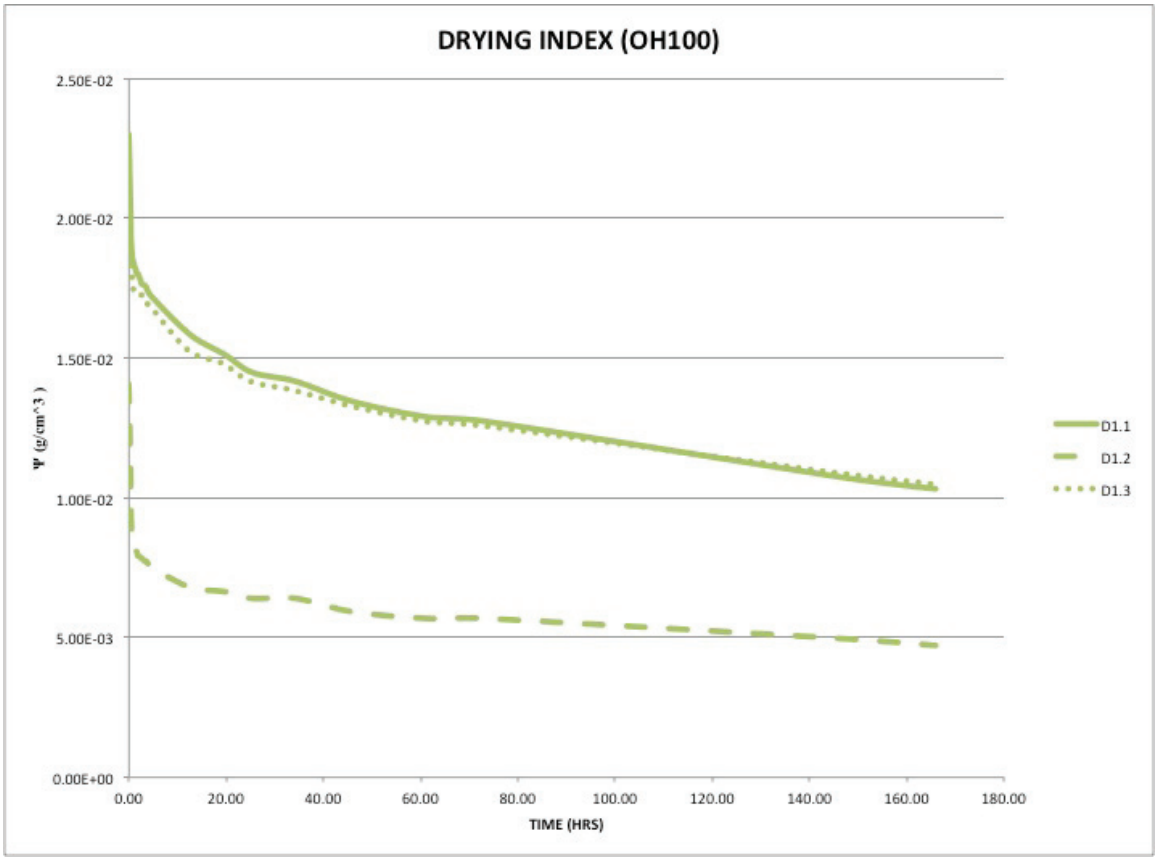
APPENDIX E: DRYING INDEX TESTING DATA

Drying Index D1.2							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
5/1/12	12:40 PM	0.00	0.00	331.25	1.76	1.41E-02	1.04E-02
5/1/12	12:43 PM	0.03	2.00	331.20	1.71	1.37E-02	1.04E-02
5/1/12	12:46 PM	0.10	6.00	331.15	1.66	1.33E-02	1.04E-02
5/1/12	12:49 PM	0.15	9.00	331.10	1.61	1.29E-02	1.04E-02
5/1/12	12:52 PM	0.20	12.00	331.03	1.54	1.23E-02	1.04E-02
5/1/12	12:55 PM	0.25	15.00	330.95	1.46	1.17E-02	1.04E-02
5/1/12	1:00 PM	0.33	20.00	330.87	1.38	1.10E-02	1.04E-02
5/1/12	1:05 PM	0.42	25.00	330.68	1.19	9.52E-03	1.04E-02
5/1/12	1:10 PM	0.50	30.00	330.62	1.13	9.04E-03	1.04E-02
5/1/12	1:20 PM	0.68	41.00	330.55	1.06	8.48E-03	2.40E-03
5/1/12	1:25 PM	0.75	45.00	330.53	1.04	8.32E-03	0.00E+00
5/1/12	1:30 PM	0.83	50.00	330.53	1.04	8.32E-03	0.00E+00
5/1/12	1:35 PM	0.92	55.00	330.53	1.04	8.32E-03	9.60E-04
5/1/12	1:40 PM	1.00	60.00	330.52	1.03	8.24E-03	4.36E-04
5/1/12	1:51 PM	1.18	71.00	330.51	1.02	8.16E-03	0.00E+00
5/1/12	2:00 PM	1.33	80.00	330.51	1.02	8.16E-03	2.67E-04
5/1/12	2:18 PM	1.63	98.00	330.50	1.01	8.08E-03	7.38E-04
5/1/12	2:31 PM	1.85	111.00	330.48	0.99	7.92E-03	1.37E-04
5/1/12	3:06 PM	2.43	146.00	330.47	0.98	7.84E-03	0.00E+00
5/1/12	3:20 AM	2.67	160.00	330.47	0.98	7.84E-03	1.50E-04
5/1/12	3:52 PM	3.20	192.00	330.46	0.97	7.76E-03	0.00E+00
5/1/12	4:12 PM	3.52	211.00	330.46	0.97	7.76E-03	2.15E-04
5/1/12	5:17 PM	4.63	278.00	330.43	0.94	7.52E-03	9.09E-05
5/2/12	1:13 AM	12.55	753.00	330.34	0.85	6.80E-03	2.24E-05
5/2/12	8:23 AM	19.70	1182.00	330.32	0.83	6.64E-03	4.22E-05
5/2/12	2:03 PM	25.38	1523.00	330.29	0.80	6.40E-03	0.00E+00
5/2/12	10:59 PM	34.32	2059.00	330.29	0.80	6.40E-03	4.09E-05
5/3/12	10:46 AM	46.07	2764.00	330.23	0.74	5.92E-03	9.61E-06
5/4/12	2:21 AM	61.70	3702.00	330.20	0.71	5.68E-03	9.61E-06
5/4/12	2:30 PM	73.80	4428.00	330.20	0.71	5.68E-03	9.61E-06
5/7/12	3:45 PM	147.10	8826.00	330.11	0.62	4.96E-03	9.61E-06
5/8/12	10:35 AM	165.92	9955.00	330.08	0.59	4.72E-03	9.61E-06

APPENDIX E: DRYING INDEX TESTING DATA

Drying Index D1.3							
Date	Actual time	Hours	Time (m)	Mass (g)	Ut (g)	Ψ (g/cm^3)	Drying Rate (g/cm^3)
5/1/12	1:03 PM	0.00	0.00	332.01	2.67	2.14E-02	9.93E-03
5/1/12	1:06 PM	0.03	2.00	331.95	2.61	2.09E-02	9.93E-03
5/1/12	1:09 PM	0.10	6.00	331.88	2.54	2.03E-02	9.93E-03
5/1/12	1:12 PM	0.15	9.00	331.82	2.48	1.98E-02	9.93E-03
5/1/12	1:15 PM	0.20	12.00	331.74	2.40	1.92E-02	9.93E-03
5/1/12	1:18 PM	0.25	15.00	331.70	2.36	1.89E-02	9.93E-03
5/1/12	1:23 PM	0.33	20.00	331.66	2.32	1.86E-02	3.84E-03
5/1/12	1:28 PM	0.42	25.00	331.62	2.28	1.82E-02	2.88E-03
5/1/12	1:33 PM	0.50	30.00	331.59	2.25	1.80E-02	8.73E-04
5/1/12	1:44 PM	0.68	41.00	331.57	2.23	1.78E-02	2.40E-03
5/1/12	1:48 PM	0.75	45.00	331.55	2.21	1.77E-02	9.60E-04
5/1/12	1:53 PM	0.83	50.00	331.54	2.20	1.76E-02	9.60E-04
5/1/12	1:58 PM	0.92	55.00	331.53	2.19	1.75E-02	9.60E-04
5/1/12	2:03 PM	1.00	60.00	331.52	2.18	1.74E-02	0.00E+00
5/1/12	2:14 PM	1.18	71.00	331.52	2.18	1.74E-02	0.00E+00
5/1/12	2:23 PM	1.33	80.00	331.52	2.18	1.74E-02	2.67E-04
5/1/12	2:41 PM	1.63	98.00	331.51	2.17	1.74E-02	3.69E-04
5/1/12	2:54 PM	1.85	111.00	331.50	2.16	1.73E-02	0.00E+00
5/1/12	3:06 PM	2.43	146.00	331.50	2.16	1.73E-02	6.86E-04
5/1/12	3:20 AM	2.67	160.00	331.48	2.14	1.71E-02	6.00E-04
5/1/12	3:52 PM	2.80	168.00	331.47	2.13	1.70E-02	2.53E-04
5/1/12	4:12 PM	3.12	187.00	331.46	2.12	1.70E-02	7.16E-05
5/1/12	5:17 PM	4.23	254.00	331.45	2.11	1.69E-02	2.02E-04
5/2/12	1:13 AM	12.15	729.00	331.25	1.91	1.53E-02	6.70E-05
5/2/12	8:23 AM	19.32	1159.00	331.19	1.85	1.48E-02	1.13E-04
5/2/12	2:03 PM	24.98	1499.00	331.11	1.77	1.42E-02	3.58E-05
5/2/12	10:59 PM	33.93	2036.00	331.07	1.73	1.38E-02	4.77E-05
5/3/12	10:46 AM	45.67	2740.00	331.00	1.66	1.33E-02	2.27E-05
5/4/12	2:21 AM	61.32	3679.00	330.93	1.59	1.27E-02	2.27E-05
5/4/12	2:30 PM	73.40	4404.00	330.91	1.57	1.26E-02	2.27E-05
5/7/12	3:45 PM	146.17	8770.00	330.70	1.36	1.09E-02	2.27E-05
5/8/12	10:35 AM	165.92	9955.00	330.65	1.31	1.05E-02	2.27E-05

APPENDIX E: DRYING INDEX TESTING DATA



APPENDIX E: DRYING INDEX TESTING DATA

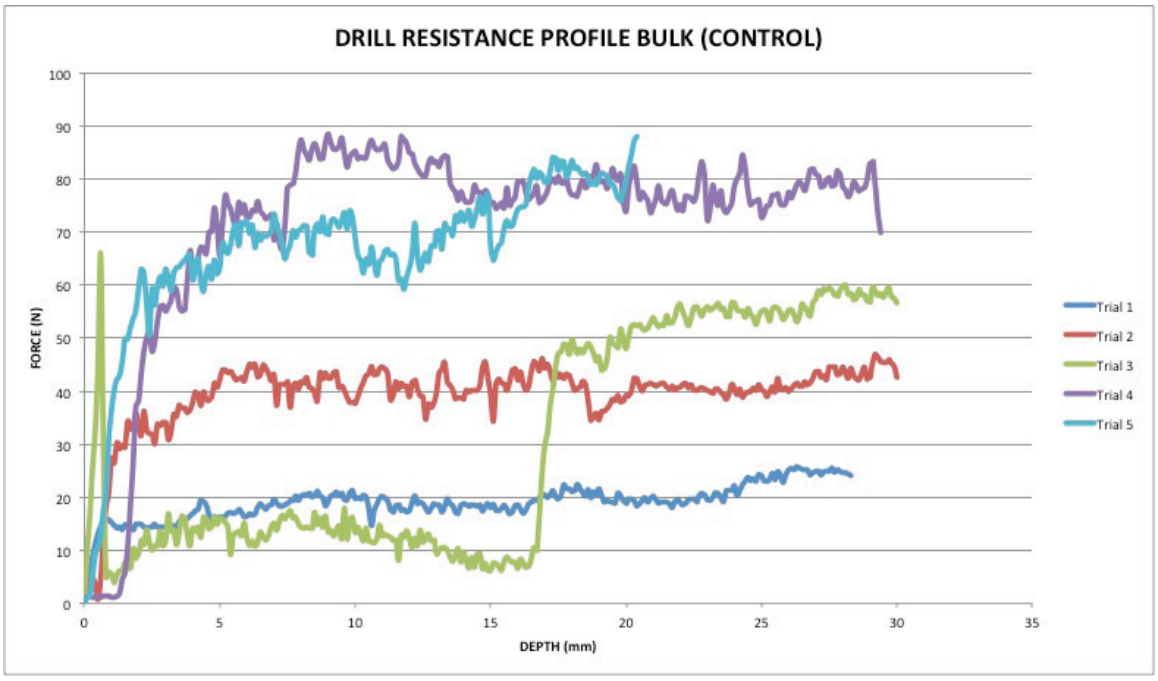
DRYING INDEX CALCULATIONS												
	A1.1	A1.2	A1.3	B1.1	B1.2	B1.3	C1.1	C1.2	C1.3	D1.1	D1.2	D1.3
Capillary Absorption Coefficient (g/cm^3)	-3.33E-04	-2.24E-04	-2.53E-04	-1.81E-02	-1.89E-02	-2.17E-02	-1.77E-02	-2.14E-02	-1.90E-02	-8.24E-03	-1.04E-02	-9.93E-03
Correlation Factor	-0.998	-0.998	-0.996	-0.997	-0.992	-0.992	-0.995	-0.998	-0.996	-0.996	-0.993	-0.997
Ψc (g/cm^3)	0.03	0.03	0.03	0.04	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.02
Uc	3.38	4.06	4.32	4.38	2.59	3.76	2.57	2.20	2.02	2.38	1.13	2.36
Uo	3.63	3.81	2.72	4.97	3.07	4.40	3.17	2.55	2.55	2.88	1.76	2.67
Wd	318.14	326.78	318.18	317.16	320.83	323.48	324.97	320.62	320.62	317.86	329.49	329.34
Final Drying Rate (g/cm^3)	-4.16E-07	-2.72E-05	-2.67E-05	-3.88E-05	-2.08E-05	-3.43E-05	-2.08E-05	-1.91E-05	-1.57E-05	-2.59E-05	-9.61E-06	-2.27E-05
Correlation Factor	-0.995	-0.997	-0.994	-0.994	-0.994	-0.995	-0.996	-0.997	-0.997	-0.999	-0.996	-0.998
Critical Moisture Content (Yc)	0.93	1.07	1.59	0.88	0.84	0.85	0.81	0.86	0.79	0.83	0.64	0.88
Critical Residual Water Content (Qc%)	1.06	1.24	1.36	1.38	0.81	1.16	0.79	0.69	0.63	0.75	0.34	0.72

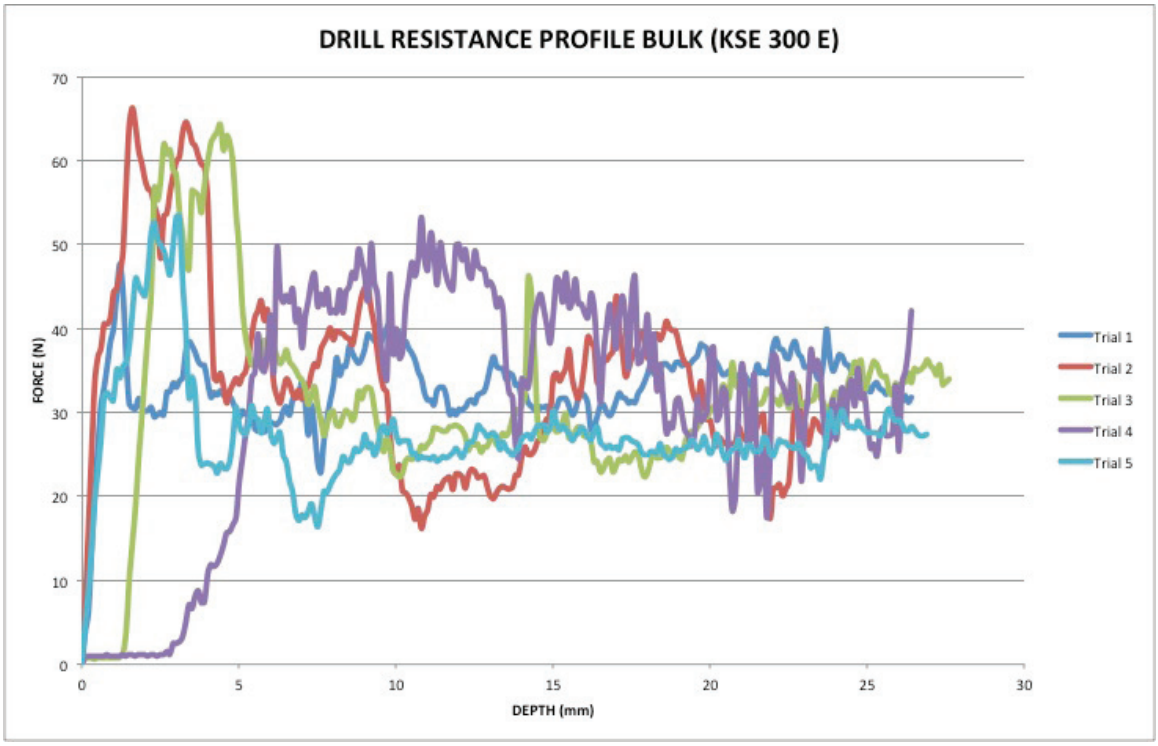
APPENDIX E:

DRILL RESISTANCE TESTING

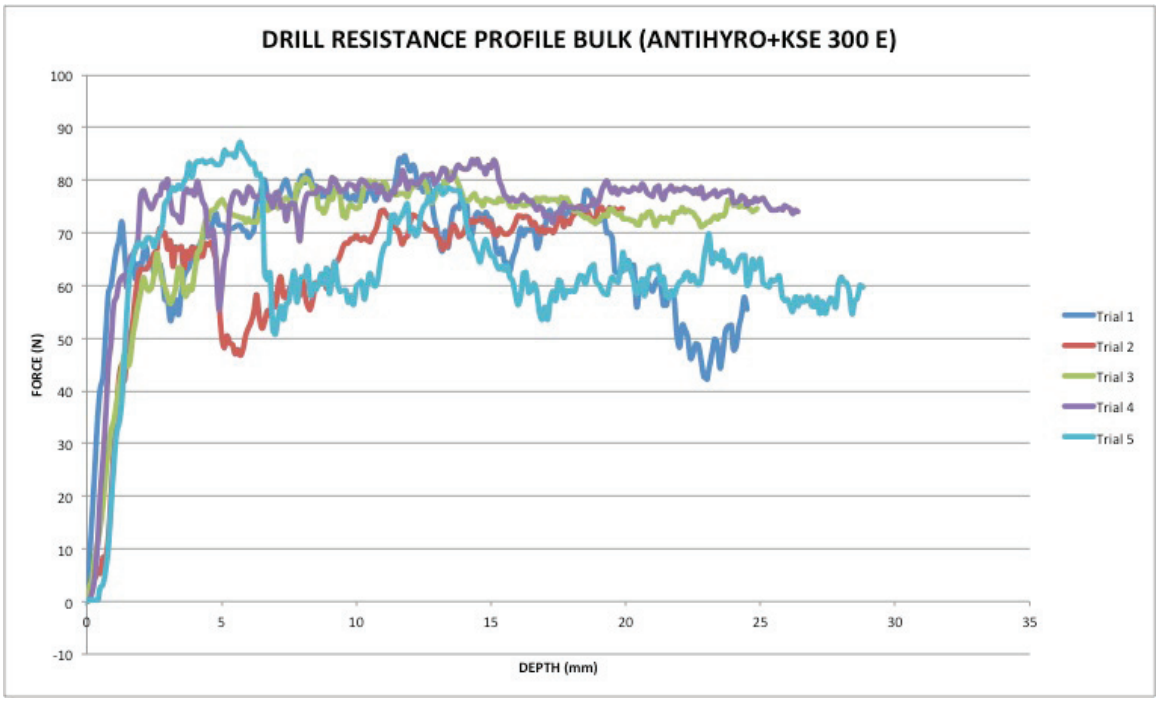
DATA

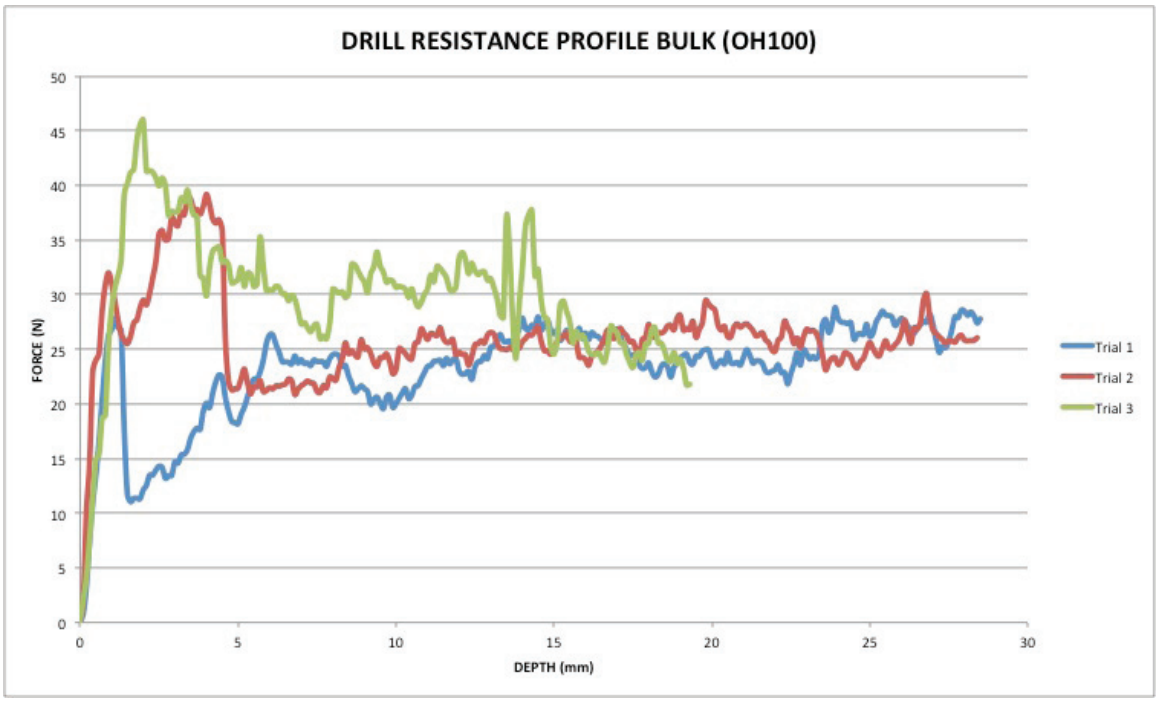
APPENDIX E: RESISTANCE DRILL TESTING DATA





APPENDIX E: RESISTANCE DRILL TESTING DATA





APPENDIX F:

TECHNICAL DATA

Technical Information Sheet
Article No. 0714

KSE 300 E

Elasticised stone strengthener on a silicic acid ethyl ester base. Gel deposit rate approx. 30%

Range of use

Remmers KSE 300 E is preferably used for friable, medium to coarse-pored sandstone, certain volcanic rock (e.g. tuff) as well as weathered brick. It can also be used for strengthening historical renders and joints. Stone that has pronounced swelling and shrinking properties due to swelling capable clay minerals must be treated first with Funcosil Antihygro (Art. No. 0616) to reduce swelling. The stone should be examined in Remmers' laboratory.

Property profile

Remmers KSE 300 E, an elasticised stone strengthener, was developed in co-operation with Dr. E. Wendler (Munich) and a work group directed by Prof. Dr. J. Grobe (Münster) within the framework of a project called "Protecting Stone Surfaces through the Application of Elastic Silicic Acid Ester" which was sponsored by the German Federal Environment Foundation (Osnabrück).
Remmers KSE 300 E differs from conventional stone strengtheners by a

- moderate E-modulus increase (stress-strain behaviour) while at the same time providing sufficient consolidation of the natural stone structure.

Remmers KSE 300 E reacts with the water or humidity stored in the pore system. During this reaction, amorphous and hydrous silicon dioxide linked through soft segments is deposited as a binder. The binder silica gel replaces the original binder lost through weathering.
The speed of the gel deposit reaction is highly dependent on temperature and humidity. Under normal conditions (20 °C, 50% relative humidity), the deposit of binder is concluded after approx. three weeks.
The most important property parameters of Remmers KSE 300 E stone strengthener are listed in the following:

Characteristic data of the product

Characteristic data of the product in the packaged state

Active ingredient content:	approx. 50% by mass
Density at 20 °C:	0.9 g/cm³
Colour:	clear, slightly yellow
Odour:	typical
Catalyst system:	neutral

Characteristic data of the product after application

Deposited quantity of gel:	approx. 300 g/l
By-product caused by the reaction:	ethanol (escapes)

- Gel deposit rate approx. 30 %
- Single component system – reliable and easy to use
- Neutral catalyst
- High penetration depth, possible all the way down to the sound core of the stone material
- No by-products that damage the building
- High weather resistance and UV stability
- Partially strengthened natural stone can be worked over with Remmers Restoration Mortar.

Directions

Preliminary examination, setting up trial areas:
The following characteristic properties of the material should be

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determined (analysis of the state of the building):

1. Moisture content, content of damaging salts, hygroscopic water absorption
2. Absorbency, capillary water absorption
3. Strength profile, depth of weathering, degree of hygroscopic swelling
4. Application rate for each area, penetration depth of the stone strengthener, resulting strength profile
5. Establishment of working operations
6. Set-up of a representative trial area which is necessary to see if there will be changes in colour and the correlation between laboratory results and the quantities and values achieved on the object.
7. Execution of treatment and application rates should be controlled and documented.

Preparing the substrate:
Surfaces to be restored often show reduced absorption capacity due to a crust of soil or different types of "patina". The cleaning measures necessary to restore the original absorption behaviour should be as gentle as possible, e.g. by spraying with cold or warm water or by steam cleaning. In case of stubborn soil, the Rotec Low Pressure Blasting Device should be preferably used or Remmers cleaning products (see the respective Technical Information Sheets).
In many cases the stone is already so friable that cleaning cannot take place without a sensitive loss of substance. To avoid this, prestrengthening with Remmers KSE 300 E or another suitable stone strengthener from the Remmers KSE family can be carried out prior to cleaning. The main strengthening measure is then carried out after the cleaned surface has dried.
In order to achieve complete saturation of the weathered zone of the stone with Remmers KSE 300 E, the surface to be treated must have reached compensation moisture balance, be absorbent and should not have been heated by the sun. When strengthening is carried out, the temperature of the stone strengthener as well as the temperature of the substrate and surrounding air should range between 8 °C and 25 °C. To avoid strong heating, use shading devices. The surfaces should be protected from sun, rain and wind before, during and after strengthening.

Application procedures:
An essential prerequisite for optimal strengthening is that the weathered zone is completely saturated all the way down to the sound core. To achieve this, Remmers KSE 300 E stone strengthener is applied to the building material in a flow coating, dipping and/or compress procedure. When using a flow coating procedure, smaller areas (if necessary, stone by stone) are treated, wet-on-wet, with KSE 300 E until the material is no longer absorbed. The procedure selected for application always depends on the task at hand.
So-called "fast hydrolysis" is not recommended since this represents an uncontrolled influence on the gel formation reaction and therefore the success of the strengthening measure.

Notes

If necessary, treatment can be repeated 2-3 weeks after initial treatment. In this case as well, saturation of the complete weathered zone must be achieved. The application rate of Remmers KSE 300 E should be determined in the laboratory during preliminary examinations and on a trial surface and will depend not only on the absorbency of the substrate but also on the application procedure selected.

Follow up treatment:
To avoid a change in the colour of the surface caused by oversaturation with Remmers KSE 300 E, the stone surface should be washed off with a dry solvent (e.g. Thinner V 101) immediately after saturation has been achieved.

Application of stone substitution compounds, hydrophobizing impregnation agents and coats of paint:
Surfaces that have been strengthened with Remmers KSE 300 E can be worked over – after the deposit of gel has been concluded – with Remmers Restoration Mortar, Funcosil impregnation agents and/or products in the Remmers Silicone Resin Paint System.
After application, the "silicic acid ester" chemical system leads to a temporary water repelling effect which disappears during the course of gel formation. If strengthened surfaces still show an annoying water repelling effect when restoration mortar is subsequently applied, this can be suppressed by wetting the surface with alcohol.

Adjoining surfaces:
Facade elements that should not come in contact with the impregnation agent such as, e.g. windows, varnished surfaces, glass and also plants should be protected by suitable measures (e.g. covered with plastic sheets).

Tools, cleaning

Depending on the task at hand, e.g. low pressure spraying equipment, airless equipment, hand sprayers. Tools and equipment must be clean and dry. After use and before longer pauses, they should be cleaned thoroughly with Thinner V 101. Once the stone strengthener has reacted, it can only be removed mechanically.

Packaging, application rate, shelf-life

Packaging:
5 l, 30 l and 200 l tin containers

Application rate:
The application rate of Remmers KSE 300 E depends to a considerable degree on the type and state of the substrate to be treated as well as the task at hand and the application technique used. The quantity required may vary ac-

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cordingly and can range between 0.1 l/m² to several litres per m².

The rate should be determined in the laboratory during preliminary examination as well as on a trial surface.

Shelf-life:
At least 12 months stored cool but frost-free and dry in closed, original containers. Remmers KSE 300 E reacts with humidity/moisture, so close containers air-tight each time material is removed.

Safety, ecology, disposal

Further information on safety when transporting, storing and handling as well as disposal and ecology is found in the latest Safety Data Sheet.

Personal protective equipment is required for spraying procedures. Use respiratory protection with a combination filter at least A/P2 (made by e.g. Dräger). For suitable protective gloves, see Safety Data Sheet. Wear closed work clothes.

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Technical Information Sheet

Funcosil®
Antihygro

Art.No. 0616

Preservative that stops swelling in natural stone which has clayey binders to reduce hygroscopic swelling.

Product base:

Alkyl ammonium compound in aqueous solution.

Property profile:

Funcosil Antihygro clearly differs in the way it works from other stone preservatives. This is an agent that reduces the hygroscopic swelling value of natural stone by approx. 50% without essentially influencing water absorption and physical-mechanical behaviour of the stone. The effect of Funcosil Antihygro is based on blockage of swelling capable centres in the sheet silicates (clay minerals). According to the knowledge we have today, swelling and shrinking processes as the result of moisture penetration and drying are seen as the primary cause of damage in clayey sandstone, but also to some extent in brick and tuff stone material. These swelling processes can occur at average to high humidity. Protective treatment with Funcosil Antihygro, especially for highly swelling capable, clayey sandstone that has little resistance to weathering because of hygroscopic swelling, is an imperative.

Characteristic data of the product in the packaged state:

Effective ingredient content:	0.2 mol/l
Density at 20°C:	approx. 1.0 kg/l
pH value:	6 ± 1
Solvent:	water
Colour:	clear
Odour:	barely perceptible

Range of use:

To be used for all porous, absorbent, cementitious building materials with a moderate to high swelling value.

Substrate conditions/Substrate pre-treatment:

A prerequisite for an optimal effect with Funcosil Antihygro is optimal penetration of the effective ingredients. To ensure this, the following points should be observed:

- The surface to be treated may not have been hydrophobically treated (water repelling); for this reason, a waiting period of 6 weeks must be observed if strengthening with silicic acid esters has been carried out.
- Alkalinity in the area of freshly filled joints may have a negative effect on the effectiveness of Funcosil Antihygro, a waiting period of at least 2 weeks must be observed after mortar consolidation measures have been carried out.
- Before applying the preservative, dirt and pollutant crusts, efflorescence and infestation with alga and moss must be removed from the surface by a suitable cleaning procedure. Cleaning opens capillaries and pores, allowing the impregnation agent to be absorbed.
- Cleaner residue (e.g. surface-active agents) must be thoroughly removed because it reduces penetration depth and therefore the effectiveness of Funcosil Antihygro.

Working instructions:

Funcosil Antihygro is to be applied in a pressureless flow coating procedure. A 30-50 cm long film of liquid on the building material surface indicates that a sufficient amount of material is being applied. If there is any difficulty wetting the building material with Funcosil Antihygro, the surface can be priorly sprayed lightly with water. During application the nozzle should be led along the facade horizontally without interruption. Dependent on the absorbency of the substrate, the process is repeated several times. As a rule, two applications are sufficient. Pressure and nozzle diameter are to be adjusted so that misting does not occur. To avoid missing areas, limited sections should be completely impregnated without interruption. For smaller, more complicated surfaces that do not allow a spray procedure, work can be carried out with a brush or, for ornamental elements, with cellulose compresses and/or a full saturation procedure. Freshly treated surfaces should be protected against driving rain and strong sunlight for at least 5 hours. For projects classified as historical monuments, we recommend preliminary examinations and trial surfaces. We would be pleased to give you advice.

Working temperature:
Treatment to reduce swelling can be executed at temperatures between 10°C and 25°C. The reaction may be delayed at working temperatures below 10°C.

Follow-up treatment:

Natural stone preservation can be executed in the Funcosil System with a measure package co-ordinated to the damage and weathering mechanism. To support the effect of Funcosil Antihygro, it makes sense in many cases to use a stone strengthener (Funcosil Stone Strengthener 300 and in some cases Funcosil Stone Strengthener 100 or Funcosil Stone Strengthener 510) and/or a hydrophobic impregnation (Funcosil SL, SNL, WS). Coloured coating of the surface can be carried out with the Funcosil Silicone Emulsion Paint System. Working details and specifications of the products named are found in the respective Technical Information Sheets.

Tools:

All non-corrosive, low pressure conveyor or spraying equipment, liquid pumps and especially the Funcosil MV2 Sprayer are suitable for working.

Packaging, application rate and storing:

Packaging: 5 l and 30 l plastic canisters

Application rate:

Rush sandstone: 1.0-4.5 l/m²
Mottled sandstone: 0.3-2.5 l/m²
Tuff: 1.0-6.0 l/m²
Brick: 0.2-3.0 l/m²

The exact requirements should be determined on a sufficiently large (1-2 m²) trial surface.

Shelf-life: At least 6 months in closed, original containers, stored cool but frost-free. Funcosil Antihygro reacts with oxygen, so close containers air-tight each time material is removed. Protect containers from strong sunlight.

Safety, ecology, disposal:

Further information concerning safety during transport, storage and handling as well as for disposal is found in the latest Safety Data Sheet.

ConserVare® OH100 Consolidation Treatment

penetrating stone & masonry strengthener

Of all materials currently and historically employed in construction, masonry is one of the most durable. What has become apparent in recent years, however, is that masonry materials are not as enduring as once believed.

Placed in contemporary urban environments, these "timeless" materials decay at an alarming rate. Some deterioration may be attributed to the masonry's natural weathering process. The majority of the deterioration, however, is the result of oversights in use and maintenance of the masonry, and of the impact that industrialization has had on our environment, i.e. "acid deposition."

The intent of all conservation treatments is to restore the structural integrity to crumbling, decaying masonry and/or provide a means of controlling future decay. The failure of many conservation treatments lies in their inherent dissimilarity to the masonry for which they are proposed as a preservative. When selecting a conservation treatment, an important consideration is to identify those treatments with physical and chemical characteristics similar to the masonry itself.

Conservare® Consolidation Treatments are based on silicic ethyl esters. Their extremely small molecular structure enables them to penetrate deeply into deteriorated masonry surfaces, collecting at contact points between individual stone grains. An internal catalyst and atmospheric humidity then convert the liquid consolidant into a glass-like silicon dioxide (SiO^2) gel which binds the stone particles together. Exhibiting chemical characteristics and thermal expansion/contraction characteristics which are virtually identical to that of natural stone, the newly deposited SiO^2 cementing matrix replaces the stone's natural cement which has been lost due to weathering influences.

OVERVIEW

Conservare® OH100 is a ready-to-use consolidation treatment that stabilizes masonry by replacing the natural binding materials, lost due to weathering, with silicon dioxide. When properly applied, Conservare® OH100 penetrates deeply, does not form a dense surface crust, and retains the substrate's natural vapor permeability.

In addition to the general consolidation of severely deteriorated masonries, Conservare® OH100 is an effective pretreatment for friable substrates that need to be strengthened before cleaning, patching or coating. Conservare® OH100 may be used on most types of natural stone, concrete, stucco, brick, terra-cotta, etc.

Conservare® OH100 is effective on unpolished marble, travertine and limestone that has been treated with Conservare® HCT (Hydroxylating Conversion Treatment).

SPECIFICATIONS

For all PROSOCO product specifications visit www.prosoco.com and click on "SpecBuilder" or "Solution Finder."

ADVANTAGES

- One component – easy-to-use. Strengthens deteriorated stone.
- Low viscosity allows deep penetration. Will not form hardened surface crust.
- The new binder is mineral – similar to the original stone – no synthetic polymers.
- Rapid tack free drying – no dirt attraction.
- Forms no by-products harmful to the masonry.
- Treated surfaces "breathe" – does not trap moisture.
- New binder is acid resistant – resists acid rain.

TYPICAL TECHNICAL DATA

FORM	Colorless to slight yellow
SPECIFIC GRAVITY	0.997
pH	Not applicable
WT/GAL	8.30 lbs
ACTIVE CONTENT	100%
TOTAL SOLIDS	43% ASTM D 5095
VOC CONTENT	>400 g/L
FLASH POINT	104°F (40°C)
FREEZE POINT	<–22°F (<–30°C)
SHELF LIFE	1 year in tightly sealed, unopened container

OH100 Consolidation Treatment

Limitations

- Effective consolidation requires thorough laboratory and field pretesting. Contact PROSOCO for information on the recommended test programs.
- Limited shelf life – remains storage stable for approximately 12 months in sealed containers. Treated areas may bond to silicone and polyurethane molds (frequently used for casting replacement stone). Use a release agent to prevent molding compounds from adhering to the treated surface.
- Not suitable for architectural concrete block and some types of marble.
- Not suitable for use on polished marble, travertine, limestone or granite.
- Will not prevent water penetration through structural cracks, defects or open joints.
- Not recommended for below-grade application.
- May not be suitable for sale in states and districts with more restrictive AIM VOC regulations. Available in regulation-exempt small container sizes. Call Customer Care at 800-255-4255 for assistance.

REGULATORY COMPLIANCE

VOC Compliance

Conservare® OH100 Consolidation Treatment is compliant with the following national, state and district AIM VOC regulations

[X] US Environmental Protection Agency

[ ] California Air Resources Board SCM Districts

[ ] South Coast Air Quality Management District

[ ] Maricopa County, AZ

[ ] Northeast Ozone Transport Commission

Manufactured and marketed in compliance with USEPA AIM VOC regulations (40 CFR 59.403). VOC Information

THE IMPORTANCE OF PRETESTING

Since building materials differ in their nature and degree of deterioration, each conservation project poses unique problems and requirements. To gain a full understanding of the ongoing deterioration and determine necessary stabilization/conservation measures, a number of laboratory and field tests are required.

Laboratory Testing

a. Evaluates the physical and chemical characteristics of the substrate(s) to confirm whether consolidation is possible.

b. Identifies the cause(s) of deterioration and surface preparation procedures necessary for conservation treatment.

c. Determines the most appropriate conservation agent(s) and field application procedures.

For more information on the recommended testing program, read the Conservare® Stone Testing Brochure and contact your PROSOCO representative to arrange a job-site visit.

On-Site Testing

Following lab testing, a test area should be cleaned and allowed to dry. An application of Conservare® OH100 Consolidation Treatment is made following specific recommendations provided by the laboratory analysis. The job site test area should be as large as possible and representative of the condition of the entire project.

The test area is necessary to confirm application procedures under job site conditions and allow calculation of the masonry's consumption rate. The on-site tests also provide a visible sample of the effects of the treatment on actual job surfaces. Additional core samples can be taken from the test area and tested to verify depth of penetration and proper application procedures.

ALWAYS TEST

ALWAYS TEST a small area of each surface to confirm suitability and desired results before starting overall application. Test with the same equipment, recommended surface preparation and application procedures planned for general application.

PREPARATION

Following lab and on-site testing, clean the building with the appropriate Sure Klean® product. In most cases, surface contaminants such as carbon crust, salts, pigeon droppings, mildew and atmospheric stains must be completely removed to assure thorough penetration of Conservare® OH100.♦ In addition, surface sealers and repellents which may have been applied must be thoroughly removed. Contact Customer Care at (800) 255-4255 for additional cleaning recommendations.

♦In cases where even the most sympathetic cleaning program would remove an unacceptable level of surface detail, Conservare® OH100 Consolidation Treatment may be applied to the soiled surface to preconsolidate the stone. If such pre-consolidation is necessary, further evaluation will be required to ensure that no undesirable reactions take place between the consolidation treatment and the surface contaminants which may interfere with further conservation measures, i.e. subsequent cleaning, general consolidation, patching/repair, etc.

Protect people, vehicles, property, metal, glass, foliage, painted surfaces and all non masonry surfaces from contact with product, fumes or wind drift. Protect and/or divert pedestrian and auto traffic.

Ensure fresh air entry and cross ventilation during application and drying. Extinguish all flames, pilot lights and other potential sources of ignition during use and until all vapors are gone. When applying to exteriors of occupied buildings, make sure all windows, exterior intakes and air

OH100 Consolidation Treatment

conditioning vents are covered and air handling equipment is shut down during application and until all vapors have dissipated.

Surface and Air Temperatures

Surface and air temperatures should be between 50–90°F (10–32°C) during application. Relative humidity should be greater than 40%. Excessive surface heating can be prevented by shading with awnings.

Protect surface to be treated from direct sunlight for several hours prior to beginning application. When possible, initiate treatment when surfaces are shaded. Keep surface temperature relatively cool to prevent too rapid evaporation of Conservare® OH100 and to ensure proper penetration. Do not apply during rain, to wet surfaces or when there is a chance of rain. Protect from rain for two days following application.

Equipment

Apply by low-pressure spray, brush or dipping. Larger surfaces should be treated using low-pressure spray equipment, small areas with spray tanks. Mobile objects such as sculptures are best treated indoors by dipping or with the use of compresses. Contact Customer Care at 800-255-4255 or your local sales manager for more information.

Storage and Handling

Store in a cool, dry place away from potential ignition sources. Keep tightly closed when not dispensing. Published shelf life assumes upright storage of factory-sealed containers in a dry place. Maintain temperature of 45–100°F (7–38°C). Do not double stack pallets. Dispose of unused product and container in accordance with local, state and federal regulations.

APPLICATION

Before use, read "Preparation" and "Safety Information."

Dilution

Use in concentrate. Do not dilute or alter. Stir or mix well before use.

Coverage Rates

Coverage rates vary depending on the substrate and degree of deterioration. Laboratory and field testing are necessary to confirm desired results and application procedures.

Application Instructions

Ensure proper penetration and prevent crust formations by applying Conservare® OH100 in repeated applications referred to as "cycles." A cycle consists of three successive saturating applications at 5–15 minute intervals. Typical treatments involve two or three cycles (6–9 separate applications). Allow 20 to 60 minutes between cycles. Laboratory testing will determine the optimum delay between applications and between cycles. Additional material should be applied until excess material remains visible on the surface for 60 minutes following the last application. Once this degree of saturation is achieved over the entire surface, the first treatment is complete. Immediately flush excess surface materials using industrial grade MEK (methyl ethyl ketone) or mineral spirits. If a second treatment is necessary, allow two to three weeks curing time following first treatment.

NOTE: Laboratory testing will determine the absorption profile and conservation capacity of the substrate(s). From this information, the optimal delay between saturating coats, and dwell time between cycles will be prescribed. The work area should be limited to a size that can be treated within the prescribed time periods.

Proper timing of the application process will maximize penetration of the consolidation treatment. Deep penetration is critical to the long-term benefits of any consolidation treatment.

BEST PRACTICES

Since building materials differ in their nature and degree of deterioration, each conservation project poses unique problems and requirements. To gain a full understanding of the ongoing deterioration and determine necessary stabilization/conservation measures, a number of laboratory and field tests are required.

Protect surface to be treated from direct sunlight for several hours prior to beginning application. When possible, initiate treatment when surfaces are shaded. Keep surface temperature relatively cool to prevent too rapid evaporation and to ensure proper penetration.

Ensure proper penetration and prevent crust formations by applying Conservare® OH100 in repeated applications referred to as "cycles." A cycle consists of three successive saturating applications at 5–15 minute intervals.

Additional material should be applied until excess material remains visible on the surface for 60 minutes following the last application. Once this degree of saturation is achieved over the entire surface, the first treatment is complete.

Never go it alone. If you have problems or questions, contact your local PROSOCO distributor or field representative. Or call PROSOCO technical Customer Care, toll-free, at 800-255-4255.

OH100 Consolidation Treatment

Cleanup

Clean tools and equipment immediately with mineral spirits, denatured alcohol or an equivalent cleaning solvent. Remove over spray and spills as soon as possible.

Post-Treatment

Areas properly treated with Conservare® OH100 can receive stone repair materials, regrouting materials and PROSOCO's BMC® silicone emulsion paints after the consolidation procedures have been completed. After curing apply the appropriate Sure Klean® Weather Seal water repellent to ensure protection from further water damage.

SAFETY INFORMATION

Conservare® OH100 Consolidation Treatment is a solvent carried product and may cause symptoms typical with organic solvent exposures. This is a combustible material. Use appropriate ventilation, safety equipment and job site controls during application and handling. Read the full label for precautionary instructions before use.

First Aid

Ingestion: If swallowed, call a physician immediately. Do not induce vomiting except at the instruction of a physician. If vomiting occurs, keep head below waist to prevent entry of liquid into lungs.

Eye Contact: Rinse eyes thoroughly for 15 minutes. Get medical assistance.

Skin Contact: Rinse thoroughly. Get medical attention if irritation persists. Launder contaminated clothing before reuse.

Inhalation: Remove to fresh air. Give artificial respiration if not breathing. Get immediate medical attention.

24-Hour Emergency Information:
INFOTRAC at 800-535-5053

WARRANTY

The information and recommendations made are based on our own research and the research of others, and are believed to be accurate. However, no guarantee of their accuracy is made because we cannot cover every possible application of our products, nor anticipate every variation encountered in masonry surfaces, job conditions and methods used. The purchasers shall make their own tests to determine the suitability of such products for a particular purpose.

PROSOCO, Inc. warrants this product to be free from defects. **Where permitted by law, PROSOCO makes no other warranties with respect to this product, express or implied, including without limitation the implied warranties of merchantability or fitness for particular purpose**. The purchaser shall be responsible to make his own tests to determine the suitability of this product for his particular purpose. PROSOCO's liability shall be limited in all events to supplying sufficient product to re-treat the specific areas to which defective product has been applied. Acceptance and use of this product absolves PROSOCO from any other liability, from whatever source, including liability for incidental, consequential or resultant damages whether due to breach of warranty, negligence or strict liability. This warranty may not be modified or extended by representatives of PROSOCO, its distributors or dealers.

CUSTOMER CARE

Factory personnel are available for product, environment and job-safety assistance with no obligation. Call 800-255-4255 and ask for Customer Care - technical support.

Factory-trained representatives are established in principal cities throughout the continental United States. Call Customer Care at 800-255-4255, or visit our web site at www.prosoco.com, to find the name of the Conservare® representative in your area.

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